Part II

Sustainability and ecodesign

BUILDING ECODESIGN THROUGHOUT THE SUPPLY CHAIN: A NEW IMPERATIVE FOR THE TEXTILE & CLOTHING INDUSTRY

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ABSTRACT

In the electronic, electrical and automotive sectors, ecodesign is becoming a necessary and accepted addition to the product development process with products now appearing on the market having significantly improved environmental performance. The drivers for this have come from legislation, increasing customer awareness, a desire for an improved environmental image and the recognition that ecodesign can reduce costs for a company. However, to date there is little evidence of a similar move towards ecodesign within the textile industry despite many supply chain members having clear environmental credentials. This paper will highlight some of the key drivers for ecodesign within the textile and clothing industry illustrating the learning that can be transferred from the other sectors adopting this approach to product development. It will introduce some of the methods that can be employed to encourage ecodesign helping to ensure that in future products from this sector illustrate clear environmental improvements to customers. With the complexity of the structure of the textile and clothing industry and the nature of environmental problems it is particularly important that all supply chain members work together to ensure that ecodesign becomes an accepted part of good product development. Such a proactive approach could result in a significant improvement of image with the consumer.

INTRODUCTION

Ecodesign as a subject has developed considerably over the last ten years with the increase in awareness of environmental issues in industry [1, 2, 3]. Until recently, the usual response to environmental problems was to reduce pollution and waste after it had been produced. Attention then moved away from these ‘end-of-pipe’ approaches to ‘cleaner’ manufacturing which results in less waste and pollution being generated. There was then the realisation that major environmental impacts arise from the material choices and from the use and disposal of products [4].

The most advanced companies are now moving beyond the compliance mentality and being proactive in shaping future markets, consumer needs and influencing legislative developments. They see environment as an opportunity rather than a threat, recognise that ‘prevention is better than cure’ and are attempting to ‘design out’ rather than simply manage the problems.

Ecodesign is understood to be the systematic integration of environmental considerations into the design process across the product life cycle, from cradle to grave [5, 6, 7]. This approach aims to reduce and balance the adverse impact of a manufactured product on the environment by considering the product’s whole life cycle (illustrated in figure 1 below) from raw materials acquisition, through manufacturing, distribution and use to final recycling and disposal.

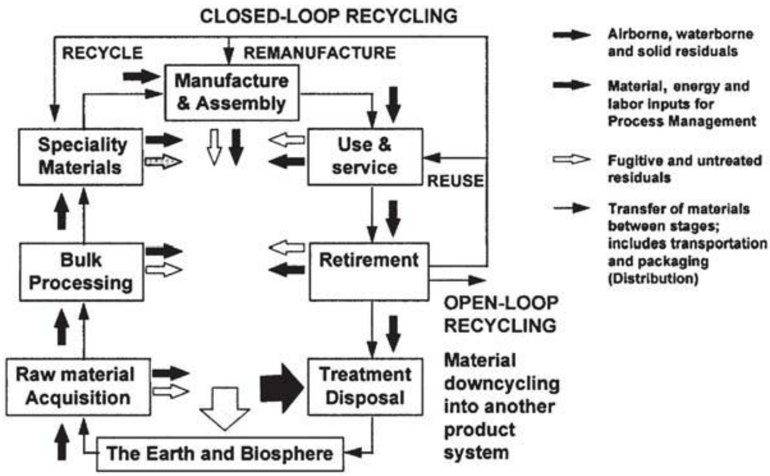

Figure 1 Product Life Cycle System [8]

There are various influences, both internal and external driving organisations towards implementing ecodesign. These are summarised as:

- Cost savings: integrating environmental issues into product development can result in cost savings such as less raw materials used, less waste produced, energy efficiency and water efficiency [9].
- Legislative regulations: these are becoming more and more important to companies as they are increasing in both the country in which they operate and to which they export [9].
- Competition: pioneering companies have realised that they may gain some competitive advantage by considering ecodesign [10, 11].
- Market pressure: Ecodesign can be an effective way to improve an organisation's environmental performance and therefore help to meet the increasing market pressure associated with the environment [9].
- Industrial customer requirements: many suppliers are now being asked to meet their customer's environmental requirements[11].
- Innovation: new market opportunities can be opened up by integrating environmental issues into product development as this stimulates product and process innovation [10].
- Employee motivation: introducing environmental considerations in a organisations is an effective way to engage and motivate employees as they can actively contribute and improve their working environment [11].
- Company responsibility: many more companies are becoming more aware of their responsibility towards the environment and the role they need to play in a more sustainable society [11].
- Communications: many organisations are using the environment as an effective communication tool with all stakeholders. It is providing a new mechanism to promote both the organisation and their products or services [7].

This mix of internal and external pressure has resulted in a real drive in many industrial sectors to consider ecodesign as an integrated part of all product development.

BACKGROUND TO ECODESIGN

The concept and practice of ecodesign is the response from the design community to increasing environmental pressures, limits and awareness. In the late 1980's and early 1990's, coinciding with the "Green Consumer" revolution [12,13], design began to be viewed as important in the development and launch of more mainstream eco-products and in enhancing consumer acceptance of these. This also helped portray an environmental profile for companies whilst applying and interpreting various new and clean technologies [14].

Definitions and descriptions of ecodesign

The last two decades have seen a proliferation of terminology relating to the incorporation of environmental considerations into design. This has included ecodesign [15]; environmentally conscious design [16]; Design for the Environment [11,17]; Life Cycle Design [18]; EcoRedesign [19]; and green, ecodesign and sustainable design [20]. Some environmentally related design terms come from Dewberry and Goggin [20]. They propose three ecodesign approaches as: green design; ecodesign; and sustainable design:

- *Green design:* has a single-issue focus, perhaps incorporating the use of some new material, such as recycled or recyclable plastic, or consider energy consumption.
- *Ecodesign:* adopts the lifecycle approach, exploring and tackling all or the greatest impacts across the products lifecycle.

Models are used to explain ecodesign in more detail and one by Brezet [21] provides a clear outline of the key design criteria and consideration. This model proposes a four-step model of ecodesign innovation and is illustrated in figure 1 below. These steps are described as:

- *Product improvement:* The improvement of existing products with regards to pollution prevention and environmental care. Products are made compliant.
- *Product redesign:* The product concept stays the same, but parts of the product are developed further or replaced by others. Typical aims are increased reuse of spare parts and raw materials, or minimising the energy use at several stages in the product life cycle.
- *Function innovation:* Involves changing the way the function is fulfilled. Examples include a move from paper-based information exchange to e-mail, or private cars to 'call-a-car' systems.
- *System innovation:* New products and services arise requiring changes in the related infrastructure and organisations. For example, a changeover in agriculture to industry-based food production, or changes in organisation, transportation and labour based on information technology are typical.

To move from level 1 to level 4, increasing amounts of time and complexity are required, which leads to higher eco-efficiency improvements. This model suggests that these more complex ecodesign innovations will (or can) only be achieved over a significant time period, say 10–20 years.

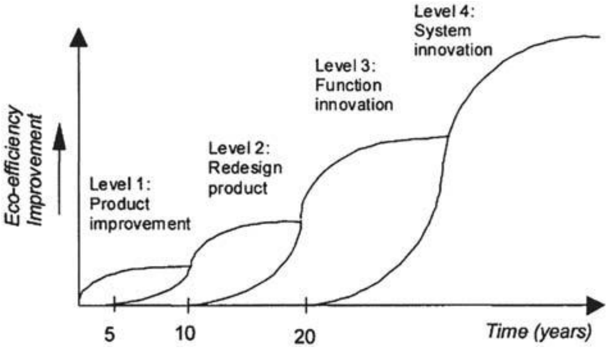

Figure 1 Four Stage model of ecodesign innovation [21].

TEXTILE & CLOTHING SUPPLY CHAIN AND THE ENVIRONMENT

It has been recognised that improving the communication and understanding between the various stakeholders within the textile and clothing sector is of paramount importance [22]. Connections have been made between communication and improved environmental performance and these suggest that ecodesigned textile and clothing products cannot be successfully developed until a deeper understanding of the supply chain is attained [22]. Designers are often isolated, for example, from the finishers and therefore unaware of the environmental demands being made to this section of the product development process. A summary of existing communication channels throughout the textile industry have been illustrated in figure 2 below.

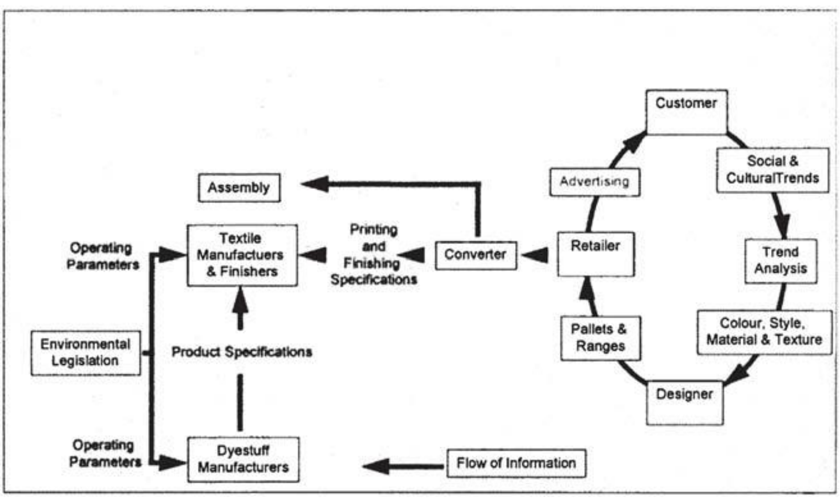

Figure 2 Summary of communication channels throughout the textile & clothing industry [22]

Figure 2 highlights the isolation of the designer and also emphasises how the designer, consumer, trend analysis and partly the retailer are divorced from the impacts of environmental legislation impacting upon operation.

Increasing environmental awareness

Within the sector and at all stages of the supply chain there has been a significant increase in environmental awareness and this is reflected in the number of companies now undertaking environmental reporting which includes setting and making public targets for improvement. This is particularly evident within retailers who are also encouraging members of there supply chain to take a similar approach [23]. However there is still very little evidence of any significant activity which takes into account the design of the products. This is surprising given that in 1997 a survey of 70 UK textile and clothing designers found that 80% of the respondents recognised that there was an increasing demand for improved environmental products [24]. Respondents of this survey also identified a number of barriers which they felt inhibited the adoption of more environmentally responsible strategies. The main ones involved:

- lack of environmental awareness and appropriate environmental information;
- lack of control over types of materials and processes used;
- lack of senior management commitment;
- concern over increased costs; and
- lack of time.

The survey also revealed that the designers perceive consumer demand to be the main driving force for improved environmental demand which at the present time appears still to be low. However there is evidence that up to 60% of the population in the UK are keen to buy environmentally improved products [25], but often struggle to find products that could be viewed as such. The main reason is that very few mainstream textile and clothing products are being designed with the environment in mind. In addition many products do not provide enough information in order to assess effectively their environmental performance. Clarifying issues to consumers through the use of care labels which identify clearly the ecological efficiency of products is necessary if any improvement is to be made.

To date, the designer has largely been perceived as the weak link in the chain of environmental improvements [26] as they are often remote from the consequences of their design specifications which may impact significantly on the environment. Manufacturers also argue that the designer's promotion of the "Ecology Look" in the late '80s and early '90s, promoting natural fabrics in earthy tones largely confused or hindered any real environmental improvements. This was because little if any consideration had been given to how the yarns, fabrics and colours were made, and the environmental impact these processes may have had.

Watson [27] also argues that the notion of 'green textiles' has trivialised the problems manufacturers have to deal with because they appear to provide instant answers, although these answers are confused. The small scale benefits of these products are being promoted when the industry has got to deal with these problems on a mass scale. Watson [27] believes that demands for the most 'environmentally friendly' fibre are unrealistic, whilst demands for the most 'sustainable process' would be more productive in improving the environmental performance of the production and processing of textile and clothing products. In the long run this will require producers and retailers, along with the designers, to work together.

ECODESIGN IN THE TEXTILE AND CLOTHING SECTOR

Although there is currently little evidence of textile & clothing designers being encouraged to consider ecodesign there is a rise in awareness both within the sector and amongst consumers. Therefore the opportunity exists for ecodesign to be implemented in a systematic fashion with the supply chain working in partnership to make it happen.

The early part of this paper demonstrated that when thinking about ecodesign consideration of the whole lifecycle of the product was key. Within the textile and clothing sectors it is only possible to consider the whole life cycle if worked from a supply chain perspective. However, in order to identify the key areas for ecodesign to focus on it is necessary to have a detailed understanding of the environmental impact of the particular product to be redesigned. There have been some studies of garments that have examined environmental impacts over the whole lifecycle and these can be a good starting point when drawing up ecodesign guidance for designers.

In their study of a woman's knit polyester blouse, Franklin Associates [28] concluded that the manufacture of the product did not have the most significant environmental impacts; these arose from the use of the product. This result is due to the laundering of the product which uses significant amounts of energy, water and detergent in its washing and ironing. Therefore one of the key considerations for designers is to ensure that these products require less of this type of 'maintenance'. However, an alterative view would be that appliance and detergent manufacturers need to improve the design of their products.

In their study of two products for Marks & Spencer, ERM [29] concluded that between 76% and 80% of the energy consumption of the garment is from the use stage with around 13% coming from the manufacture of the product itself. This again provides designers with clear targets for redesign. The problem with both these studies is that they do not highlight any environmental problem that could be occurring at the raw materials or production stages of the life cycle and therefore it becomes very difficult to enable designers to design out these environmental problems.

Brown and Williams [30] however present a useful checklist for an "ideal" garment based on their experience within Patagonia which covers all stages of the life cycle and therefore provides designers with more direction. This checklist approach is useful however the way in which design within the sector is currently organised (see Figure 1) and is likely to make it difficult for designer to both understand the particular environmental problem and to find a way in which they can affect it. For example one item in production part of the checklists identifies zero-waste as a target. This may be difficult for the designer to address but could be incorporated into the customer's purchasing policy.

One organisation that has managed to incorporate some elements of ecodesign into their products is Interface Fabrics [31]. This company has made a range of substantial environmental improvements through the implementation of an Environmental Management Systems (EMS) and one of these was to develop a new "eco-product" every year. This has led to a number of products manufactured from 100% recycled materials such as polyester fibre produced from post-consumer PET bottles and woollen products made from reclaimed Ministry of Defence sweaters and hosiery [31]. Other areas of improvement that have been influenced by ecodesign is packaging were many opportunities for re-use of materials were identified and have been introduced [31].

CONCLUSIONS

The first part of this paper outlined the experience in ecodesign gained within other sectors of the last twelve years. It has taken time for companies to understand the subject, identify how it can be implemented and to begin to develop suitable methods and tools for designers so that ecodesign can become an integral part of their designing. Consequently, there are now product and services on the market that fit within all levels of Brezet's model [21], this is now showing that higher levels of eco-efficiency can be achieved.

The textile and clothing sectors however appears to be a long way from this. There is little evidence of companies integrating ecodesign in any way at all and very few examples of products on the market where this has been a core consideration in design. As illustrated earlier it is believed this is due to the complexity of the supply chain and the relative isolation of some designers from the supply chain. Despite these reasons this cannot continue as customers are becoming more aware of environmental issues and even beginning to base purchasing decisions on these considerations. In addition, the electrical, electronic and automotive sectors now face 'Producer Responsibility' Legislation, making them responsible for their products at the end of life, how long will it be before the textile and clothing sector faces similar legislation? The sector will be ill-prepared when this comes along.

The few examples of ecodesign that currently exist from the sectors are clearly in the first two levels of Brezet's model [21], product improvement and product redesign, where eco-efficiency gains are at their lowest. The sector therefore has a long way to go to catch up with the levels of eco-innovation being achieved elsewhere. There is clearly a lack of tools and methods available for designers for the textile and clothing sector which may be hindering its implementation but this lack of development is likely to be due to lack of demand. If companies from the sector required these tools for their designers, they would become available.

As outlined earlier in this paper it is imperative that all the supply chain impacts are understood by designers and they then find ways to design out these environmental problems. Consequently opportunities now exist for research partnerships between academia and the sector in order to better understand the impacts and develop suitable tools and methods for designers. In addition, as textiles and clothing are part of a complex chain which also include maintenance (i.e. laundering), new partnerships must emerge between the sector, appliance manufacturers and detergent manufacturers if environmental impacts are to be significantly reduced.

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SUPPLY CHAIN PARTNERSHIPS FOR SUSTAINABLE TEXTILE PRODUCTION

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INTRODUCTION

In the latter half of the 20th Century company director's performance and bonuses were assessed on the basis of whether they had succeeded in building "Long Term Shareholder Value". But financial mismanagement as evidenced by major corporations such as Enron, Worldcom, and more recently Shell, has given weight to those who argue that companies, especially multinational companies, and their directors, have a much wider responsibility than simply to shareholders.

The term the Triple Bottom Line was coined to describe company accountability not only in financial terms to shareholders and investors but also in social terms e.g. acceptance by the communities in which the firm operates, and in environmental terms by assessing the impact on the environment of the firm's own activities, or the activities of the manufacturing chain which supplies the products that the firm sells.

Consumer expectations of company behaviour have increased and not only in the rich G8 countries. In a millennium poll in 23 countries 60% of 25,000 consumers said they expected businesses to tackle the issues of fair labour practices, business ethics and environmental degradation in addition to delivering profits and jobs

So how does this affect the clothing and textile industry? In their book entitled "Sustaining the Rag Trade" published in 2000 by IIED, Roberts and Humphries identified four key elements of the sustainability of the clothing supply chain. These were:

- Eliminating environmental hazards
- Improving energy and water efficiency
- Cutting pollution and waste
- Establishing social justice

In addressing the wet processing stage of the clothing supply chain the issues shown in Table 1 were identified by the authors under each of the four headings.

Table 1. Key Sustainability Issues in Dyeing & Finishing

Environmental Hazards	Carcinogenic, toxic and allergenic dyes Use of PCP and formaldehyde in finishing
Materials Efficiency	High water consumption for dyeing High energy use for dyeing and finishing
Pollution and Waste	Biodegradation of surfactants Emissions from chlorine bleaching Effluent from unfixed dyes
Social Justice and Equity	Child labour, job security, equal opportunity, wages, working hours, freedom of association, collective bargaining

Careful selection of dyes and chemicals can play a decisive role in addressing the first three of these issues (the social justice issues are outside the scope of this paper).

Until very recently, companies have tended to address social and environmental issues separately although the Corporate Responsibility (CR) paradigm is beginning to bring these two strands closer together both conceptually and organisationally in many leading companies. In the apparel and clothing supply chains the social concerns have been primarily addressed at the level of the garment suppliers through individual company Codes of Conduct, or cross-sector codes such as the Ethical Trading Initiative, or through standards such as AA1000 or SA 8000.

The focus of companies environmental concerns has widened from the companies' own activities e.g. distribution, packaging waste, energy efficiency to that of the environmental impact of the product supply chain and the potential for chemical contamination in the final consumer article. From this viewpoint the important developments have occurred in Environmental Management Systems (EMS) and ecolabel schemes, as well as company-specific Restricted Substances Lists (RSLs).

We can now go on to look at the key environmental drivers affecting the textile supply chain.

KEY ENVIRONMENTAL DRIVERS IN THE TEXTILE INDUSTRY

Legislation

There are two main types of legislation which impact on the textile industry and the dyestuff and chemical companies who supply it:

- chemical control legislation and
- pollution control legislation.

Chemical control legislation affects the innovation, classification and labeling, supply and use of textile dyes. The most notable pieces of European legislation are the Dangerous Substances Directive (67/548/EEC), the Dangerous Preparations Directive (1999/45/EC), and the Marketing & Use Directive (76/769/EEC) and their subsequent adaptations to technical progress (ATPs) and amendments. In the United States similar controls exist through the Toxic Substances Control Act (TSCA).

In October 2003, after a period of internet-based public consultation the European Commission published its proposals for a major revision of chemical legislation in Europe. The new chemical policy is known as REACH (the Registration, Evaluation, and Authorisation of Chemicals) and is expected to come into force across the enlarged EU sometime in 2006.

The other major area of environmental legislation impacting on the textile industry is pollution control legislation which affects the use and disposal of textile dyes as well as addressing water and energy consumption, air pollution, waste water treatment and waste disposal. The most important items of European legislation in this area are the IPPC Directive, the Urban Wastewater Treatment Directive and the Water Framework Directive.

Azo dye legislation

On the 15th July 1994 the German government enacted legislation effectively banning the use on certain consumer goods of azo dyes, which could undergo reductive cleavage of the azo bond(s) to release any of 20 specified aromatic amines which were known or suspected carcinogens.

The EU harmonising legislation, the 19th Amendment to the Marketing and Use Directive (azocolourants) (2002/61/EC), came into force in 2003. The major European dye stuff manufacturers no longer produce dyes affected by this legislation eg benzidine-based direct dyes which were found to be carcinogenic over 30 years ago. However a large number of smaller manufacturers in Asia still produce these dyes.

Ecolabels

Over the last 10 years the development of various eco-labelling schemes, designed to assure consumers of the safety and environmental acceptability of a particular product, has raised the profile of environmental issues within the textile chain. The most successful of the textile eco-labelling schemes has been the Oeko-tex Standard 100 scheme run by the independent "International Association for Research and Testing in the Field of Textile Ecology" and operated by franchised testing institut in Europe, USA and Asia. Over 6000 companies worldwide have been awarded Oeko-Tex Standard 100 certfication.

By comparison the official EU scheme for textiles has been largely ineffective due to its complexity and cost. Only 53 EU ecolabels have been awarded for textile products since the criteria were established in 1999.

Oeko-tex Standard 100 is in fact a "Human Ecology" label as it is only concerned with possible negative effects of textiles on the health of the wearer. The latest version of the Standard has four basic product categories:

- Babywear
- Textiles in contact with the skin
- Textiles not in contact with the skin
- Household textiles

and limit values for chemical residues and fastness criteria are laid down for each of the product categories. The specification for baby wear is the most demanding. The parameters most affected by the coloration stage, and therefore critically affected by the choice of dyes and chemicals, are those covering heavy metals, carcinogenic dyes, allergenic dyes and colour fastness.

Environmental Management Systems (EMS)

Alongside the development of product-related ecolabels there has been a parallel growth throughout the 1990s of Environmental Management Systems which focus more on how a company manages the environmental impact of its activities as a whole rather than on the detailed assessment of individual products.

The British Standards Institute (BSI) launched the world's first Environmental Management Standard BS 7750 in 1992. Shortly after the introduction of BS 7750 the European Commission created the Eco-Management Audit Scheme (EMAS) by Regulation No 1863 in 1993. EMAS is based on the same principles as BS 7750 but additionally requires the publication of statement of environmental performance that has to be independently verified.

The international standards body ISO responded to the lead of BSI and others by developing an equivalent international standard ISO 14001 in 1996. In the same way that ISO 9001 is meant to signify a quality-oriented organisation so ISO 14001 is intended to mark out companies with a systematic approach to environmental management and a commitment to reducing the environmental impact of their operations. Recently there has been a rapid uptake of ISO 14001 by manufacturers in Asia as a means of assuring European and N. American procurement managers of the environmental probity of their operations.

A common feature of all the standards is the emphasis on external audit and accreditation by authorised bodies. Furthermore, ISO 14001 is also an effective mechanism for transmitting environmental issues along the supply chain as it requires an organisation to question its suppliers on their environmental performance and in best practice companies leads to a dialogue on key environmental issues affecting the vendor—buyer relationship.

Retailers

Several leading clothing suppliers and retailers in Germany were involved in the early discussions about textile ecolabels and started to include product safety or human ecology specifications into their supplier manuals from the late 1980's onwards. Companies such as Quelle, Otto, Steilmann and Karstadt & Neckarmann developed standards or eco-specifications similar to that of the fledgling Oeko-tex 100. This trend was given further impetus in 1994 by the introduction in Germany of the amendment to the Consumer Goods Legislation which banned the use of certain azo dyes.

From the early 1990s onwards, starting in Germany and Scandinavia, the mail order houses and clothing retailers began imposing chemical and environmental restrictions on suppliers in order ensure product safety standards and address the increasing concern of consumers for environmentally friendly goods.

The approach of the leading UK retailer Marks & Spencer was rather different to that of continental firms in that it introduced an Environmental Code of Practice in 1995 encompassing the whole of its textiles business not just for special eco-brands or lines.

In contrast C&A adopted the Oeko-tex ecolabel as its corporate standard and began rolling it out across various products in-store. These are identified as "safer clothing" options for the consumer by the use of an additional swing ticket bearing the Oeko-tex slogan "Confidence in Textiles" and the Oeko-tex logo. It has to be said that since the withdrawal of C&A from the UK in 2000 the Oeko-tex label is now virtually invisible on British High Streets.

Green Consumers

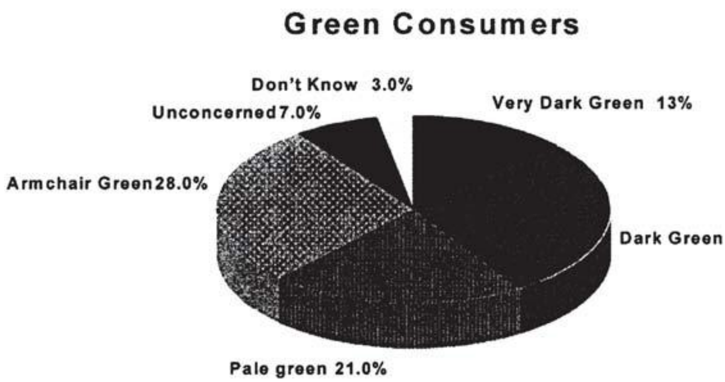
The 1990s have been dubbed the green decade by some commentators. The speed at which the environment has become a central commercial issue has left many businesses and industries unsure of their response. There has been tremendous growth in membership of green groups in the UK from the archly conservative eg the National Trust whose membership doubled from 1 million to 2 million in the 90s to the more radical groups such as Greenpeace and Friends of the Earth. At the same time there has been a huge expansion in environmental consultancy and environmental technology businesses as new opportunities opened up for companies previously confined to the relatively unglamorous waste disposal industry.

But perhaps the greatest revolution has been in public awareness and concern for the natural environment and the willingness of consumers to exercise a choice in favour of products that don't "cost the earth". In the UK context, an influential book in this greening process was the publication in 1998 of The Green Consumer Guide which became a popular best-seller. The following year the Green Party gained an astonishing 15% of the vote in the European Parliament Elections.

Each year since 1988 the well-respected polling organisation MORI has conducted an annual survey of Business and the Environment and their report includes a description of a typical British green consumer eg

- Regularly uses a bottle bank
- Take own waste paper for recycling
- Buys organically grown food
- Uses unleaded petrol
- Avoids products of companies with poor environmental record

Its 1997 report identified 37% of the population as green consumer activists based on a sample of 2000 adults. Another survey in 1995 identified different types of green consumerism in the UK.



Armchair Greens
These people state that they are concerned about the environment but this concern does not carry through into their lifestyle or purchasing behaviour

Pale Greens
This group is concerned about the environment and if offered a choice between two similar products at the same price will opt for the one that is marketed as environmentally-friendly

Dark Greens
These people are concerned about the environment and are willing to pay a premium for goods and services that they believe have a reduced environmental impact compared to conventional products.

Very Dark Greens
These people will only buy what they consider to be natural or organic products and are often to be found protesting against motorway extensions, nuclear installations, GM crops etc.

Pressure groups

The membership of environmental pressure groups and NGOs has grown rapidly in the last 10 years. The more activist groups target high profile multinational companies in order to challenge them not only on the environmental impact of their own operations but also that of their suppliers.

The focus of the Clean Clothes Campaign is more on social conditions in the garment and footwear manufacturing factories supplying famous brands such as Nike, Gap, Adidas etc. Such groups are becoming more influential as "Corporate Social Responsibility" and "Sustainable Development" move up the agenda of the large multinational companies.

Ethical Corporation Magazine has organized Conferences on CSR in Asia, Europe and N. America addressing the issues of CSR in the Supply Chain and leading companies have been quick to use the opportunity to present themselves as leaders in the field e.g. Hennes & Mauritz, Marks & Spencer, and Nike in the apparel area. Another indicator is that membership by major retailers of the Ethical Trading Initiative has increased steadily in the last few years with Gap Inc joining recently. Similar organizations have been established in the US e.g. Fair Labor Association, etc.

Friends of the Earth has recently published its second report on how retailers in the UK rate on managing risky chemicals in their supply chains. It is no surprise to find companies such as Ikea and Marks & Spencer are near the top of the league table as they have been managing these issues for a decade or more and have the added advantage of dealing exclusively in own-brand products.

Greening the textile and clothing supply chain

The textile supply chain is a classic example of a "Buyer-Driven Global Commodity Chain" (Gereffi, 1994) in which it is the large retail groups and brand name marketers in N.America and Western Europe who exercise the greatest influence on the specification of the goods they source, increasingly from the Asia Pacific region.

Due to the globalisation of the textile supply chain, and consumer/NGO pressure on "Corporate Responsibility" in Western markets, environmental drivers have been communicated to all the major textile and clothing producing regions of the world.

So even if an individual producer country does not have tough pollution control legislation or liberal labour laws, minimum standards of working conditions and safety, health and environmental requirements may be imposed by the European or North American purchasing organisation.

What is the role of the dyestuff supplier in "Greening the Textile Supply Chain"?

An initiative adopted by the chemical industry internationally termed "Product Stewardship" (as part of the Responsible Care programme) is based on the idea that the manufacturer's responsibility for the product does not end when the delivery truck leaves the factory gate. It requires suppliers to be proactive in providing information to customers on the health, safety and environmental impacts of their products in the context of their storage, use and disposal. Environmental responsibility should characterise all the major functional activities of the company and extend across the whole life-cycle of the product from "cradle to grave".

In DyStar we have developed a coloration ecology concept which recognises the environmental influences acting on our customers and seeks to build the most important issues and concerns into the key business processes of innovation, manufacturing and sales & marketing in order to deliver new products, application processes, technical service and product information which meets the customer's needs.

Controlled coloration

There are two basic approaches to pollution control

- effluent treatment—or end-of-pipe solutions
- waste minimization—or source reduction solutions

The first approach has no financial payback and is literally money down the drain. The Waste Minimisation approach not only reduces environmental impact but also delivers reduced costs—the so-called "Win-Win Scenario".

Dyestuff companies generally do not supply effluent treatment solutions although they may offer general advice on the treatability of their products. DyStar's expertise is in the invention, manufacture and application of textile dyes. Our pollution control solution is either a waste minimisation, or a clean production, solution based on the concept of Controlled Coloration. The way we deliver this is by environmentally-oriented product and process innovation.

Controlled coloration permits textile coloration processes to be carried out in a way which minimizes impact on the environment. The controls which the dyestuff manufacturer can exert are:

- Control of dyeing behaviour
- Control of product quality
- Control of application processes
- Control of environmental impact

For example some of the factors which must be taken into account when designing reactive dyes for reduced environmental impact are:

- Careful choice of intermediates—no banned amines, minimum AOX
- High colour yield—high fixation multifunctional dyes leading to reduced levels of colour in effluent
- Suitability for ultra low liquor ratio dyeing machinery—to minimize energy, water and chemicals consumption
- "Right First Time" dyeing through dyestuff compatibility—to minimise wasteful shading additions or reprocessing

Eco-Innovation (making products cleaner by design) has a major role to play in "Greening the Supply Chain" and ensuring that a greater degree of resource efficiency or resource productivity is available to the textile wet processing sector. The environmental problems facing the textile wet processing industry cannot be solved using outdated products, processes or machinery. Innovation is required to address the environmental issues facing the supply chain and dyestuff manufacturers have a key role to play.

Using a Life Cycle Assessment approach within our coloration ecology concept we have developed a number of new product ranges to address the environmental issues affecting particular fibre dyeing segments of the industry.

Some examples of recent DyStar innovations are

- High fixation reactive dyes for reduced dyeing cycles and minimum colour in effluent

- Novel disperse dye chemistry to achieve high fastness without the need for reductive clearing
- Metal-free reactive dyes for wool—an environmentally-friendly alternative to chrome dyes

However one example of environmentally-oriented product innovation deserves special mention—the Procion XL+ dyes.

Let's just look at what one of the leading business thinkers has to say about the relationship between innovation and environmental improvement. Professor Michael Porter of Harvard Business School has written influential books on Competitive Advantage, not only between companies but also between nations. In an article in 1995 he underlined the need for innovation to raise "resource productivity":

"Increasingly the nations and companies that are the most competitive are not those with access to lowest-cost inputs but those that employ the most advanced technology and methods in using their inputs…environmental progress demands that companies innovate to raise resource productivity—and that is precisely what the new challenges of global competition demand"

DyStar's Procion XL+ dyes were designed to do just that by permitting shorter dyeing cycles on cellulose textiles (minimum prepare or scour dye methods). This leads to enhanced productivity and reduced water and energy consumption. As a consequence, DyStar has won two prestigious awards for the development of this dyestuff chemistry and the application processes it facilitates. In order to deliver environmentally-oriented process innovation we work closely with leading textile machinery and equipment suppliers. Examples of optimised application processes developed in partnership with third party technology suppliers were showcased on the DyStar stand in 2003 at the International Textile Machinery exhibition at the NEC, Birmingham

CONCLUSION

The combined effect of the drivers referred to in the preceding discussion has been to raise the profile of environmental issues within the industry—a process which has been described as "Greening the Textile Supply Chain". Due to the globalisation of the textile supply chain these environmental drivers have been communicated to all major textile and clothing producing regions of the world.

At DyStar we believe that globally co-ordinated supply chain partnerships operating at a local level are essential for the realization of sustainable textile production. Only by all the actors in the textile supply chain working together can environmental improvement be promoted through the introduction of ecologically-optimised products and cleaner production techniques.

By establishing such co-operative supply chain partnerships the industry will be better equipped to respond to the environmental challenges it will face in the 21st century.

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MOLECULAR MANUFACTURING FOR CLEAN, LOW COST TEXTILE PRODUCTION

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ABSTRACT

Molecular manufacturing is an emerging technology that is being developed to build large objects to atomic precision, quickly and cheaply, with virtually no defects. When it matures, it promises to be an energy efficient and environmentally benign way to make textiles and textile products.

Current efforts to apply nanotechnology to textiles promise exciting innovations such as:

- Lightweight nanotube fibers stronger than steel
- Fabrics able to sense temperature and control their breathability
- Clothing able to sense injury and provided immediate delivery of medication to a wounded soldier

However, molecular manufacturing will provide atomic control over the structure of a fabric, promising revolutionary changes far beyond current advances:

- A garment could programmably increase or decrease its own size as needed
- A fabric could change its own color and patterns on demand
- The breathability of a textile could be variable and self-regulating
- By integrating molecular robotic components into the material, a fabric could be made to be self-cleaning and self-repairing
- A fabric could be programmed to move on its own accord, creating effects such as a flag flapping even without a breeze
- Molecular fasteners could create new clothing design options for truly seamless garments.

This paper summarizes recent advances in molecular manufacturing that are enabling the development of this radical new vision for the future of textile design and manufacture.

BACKGROUND

Although the term "nanotechnology" is now used to describe a broad and diverse range of technological areas, it was originally used to describe a novel method of manufacturing first articulated by Richard Feynman: that molecular machines should be able to build substances by mechanically placing each atom into position exactly as specified [1]. More recently, Eric Drexler has provided a compelling vision of how massively parallel arrays of molecular assemblers could build large, atomically precise objects cheaply and quickly [2–5]. The envisioned products of these molecular manufacturing systems include:

- powerful desktop computers with a billion processors
- abundant energy with inexpensive, efficient solar energy systems

- cures for serious diseases using nanorobots smaller than cells
- new materials 100 times stronger than steel
- a clean environment with nanomachines to scavenge pollutants
- more molecular manufacturing systems (they could build copies of themselves)

Since 1986 this vision of molecular nanotechnology has captured the public's imagination and is now an integral part of popular culture. References to nanomachines are standard fare in many well-known science fiction books, movies, and television shows. Encyclopedias and children's books feature Drexler's colorful and atomically-accurate designs of molecular gears and bearings, as well as artist's renditions of (often fanciful) nanomedical devices cleaning a blocked artery or killing a virus. Today's generation is expecting some form of this vision to happen in their lifetimes.

By contrast, the scientific community has been less than embracing of these ideas. Some scientists claim that this technology is either so distant in the future that we need not concern ourselves, or fundamentally impossible and will never happen. The engineering community has been for the most part silent about the controversy, which is really quite interesting because the proposed technology has very little to do with new science and everything to do with engineering analysis, design, and construction.

My assessment is that although progress is slower than it could be if we had some more focused efforts, there have been significant advances and we will likely see a functioning molecular manufacturing system by the year 2015. In this paper I provide a brief synopsis of the molecular manufacturing vision, show that recent advances and new tools have brought us *past the threshold* of the era of molecular machines, and offer a rather modest vision of what the textile community could do with a desktop manufacturing system that can precisely tailor the molecular structure of a fabric and create *inexpensive* textile products with imbedded:

- nanocomputers and molecular memory
- nanosensors
- micro- and nanomotors and actuators
- solar energy collectors
- wireless receivers and transmitters
- micro and nano-plumbing
- video displays
- energy storage devices

MOLECULAR MANUFACTURING

Molecular manufacturing is a method conceived for the massively parallel processing of individual molecules to fabricate large atomically-exact products. It would rely on the use of many trillions of molecular robotic subsystems working in parallel to process simple chemicals into new materials and devices. Built to atomic specification, the manufactured products would exhibit significantly higher performance than that of today's products. Equally as important, the high level of automation of the manufacturing process would significantly lower the cost compared against today's techniques. A distinguishing feature of molecular manufacturing would be that the trajectory and orientation of every molecule in the system are precisely controlled during the manufacturing operation, differentiating it from processes based on solution chemistry where molecules bump against each other in random orientations until reactions occur.

A few of the key concepts from the principal reference, *Nanosystems,* are summarized in Figures 1–3. Figure 1 shows a cylindrical bearing, a differential gear, and a schematic of a molecular sorting and conveyor transport system. The design and performance of the first two mechanical parts have been studied in detail, and show that high efficiencies are possible when complementary atomic surfaces are properly matched. Figure 2 shows a schematic of a stiff robotic arm composed of about four million atoms. Simple hydrocarbon molecules are fed to its tip through an internal conveyor system; atoms are transferred from those molecules to the workpiece at processing speeds approaching 500,000 atoms/second—about the speed of a fast enzyme. The other diagram shows how assembly stations could be arranged to construct small components at the densely-branched tips and the feed those products into successively larger sub-assemblies. Figure 3 shows a conceptual diagram of a desktop molecular manufacturing system. Simple hydrocarbon molecules are sorted, attached to conveyors, positioned, and then reacted to build up atomically exact structures.

It is particularly appropriate to be discussing this technology with the textile community audience at Ecotextile 04. Of all the manufactured products that come to mind, there is no better analogy to molecular manufacturing than the production of textiles, which assembles tonnage quantities of material from small fibers using up to tens of thousands of machines operating in parallel. It is also relevant to note how clean molecular manufacturing is expected to be—while these systems would manufacture products to atomic specification, they would also prepare waste products to atomic specification. Water vapor and carbon dioxide would be typical waste-stream constituents.

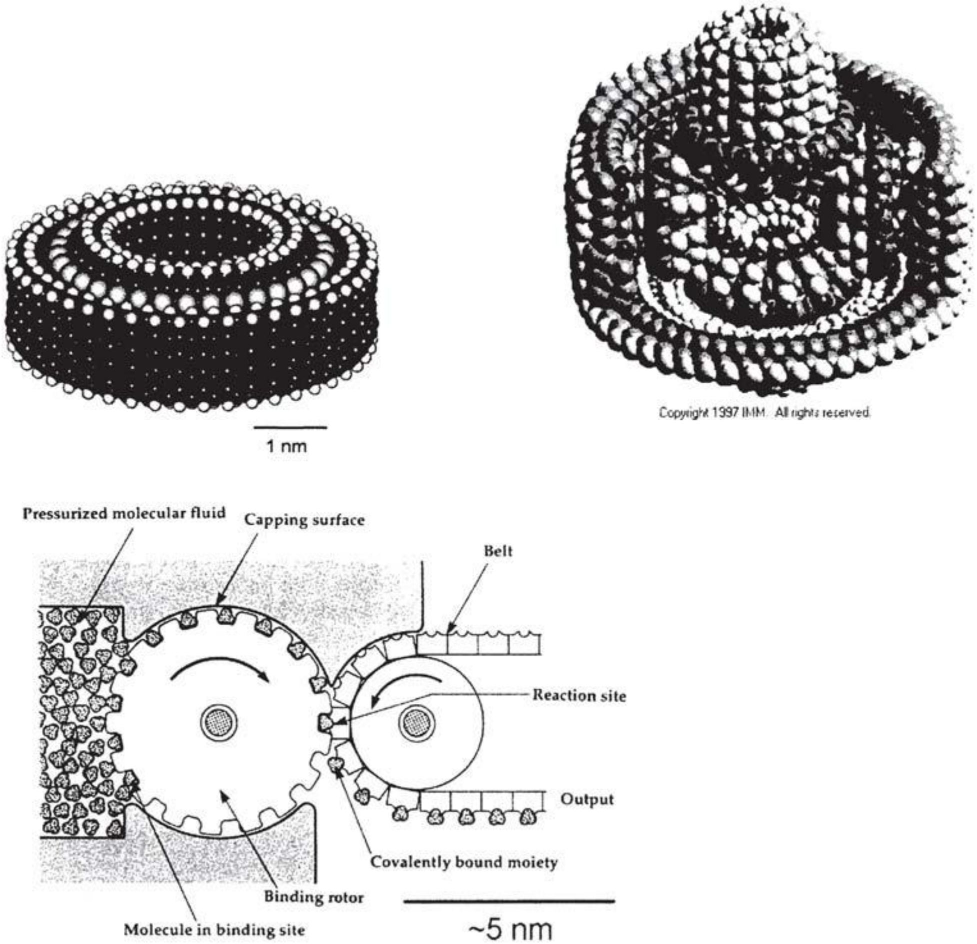


Figure1. Molecular mechanical components of increasing size and complexity. Electromechanical systems will be constructed at the molecular scale, including: support structures, rods, shafts, gears, bearings, conveyors, nanomotors, and manipulators. With proper design and built to atomic specification and precision, sliding surfaces would have low friction and gears and nanomotors would have high power conversion efficiency. The designs shown employ C, H, O, S and N atoms. *Sources: K.E. Drexler, Nanosystems [5], and the Institute for Molecular Manufacturing (www.imm.org).*

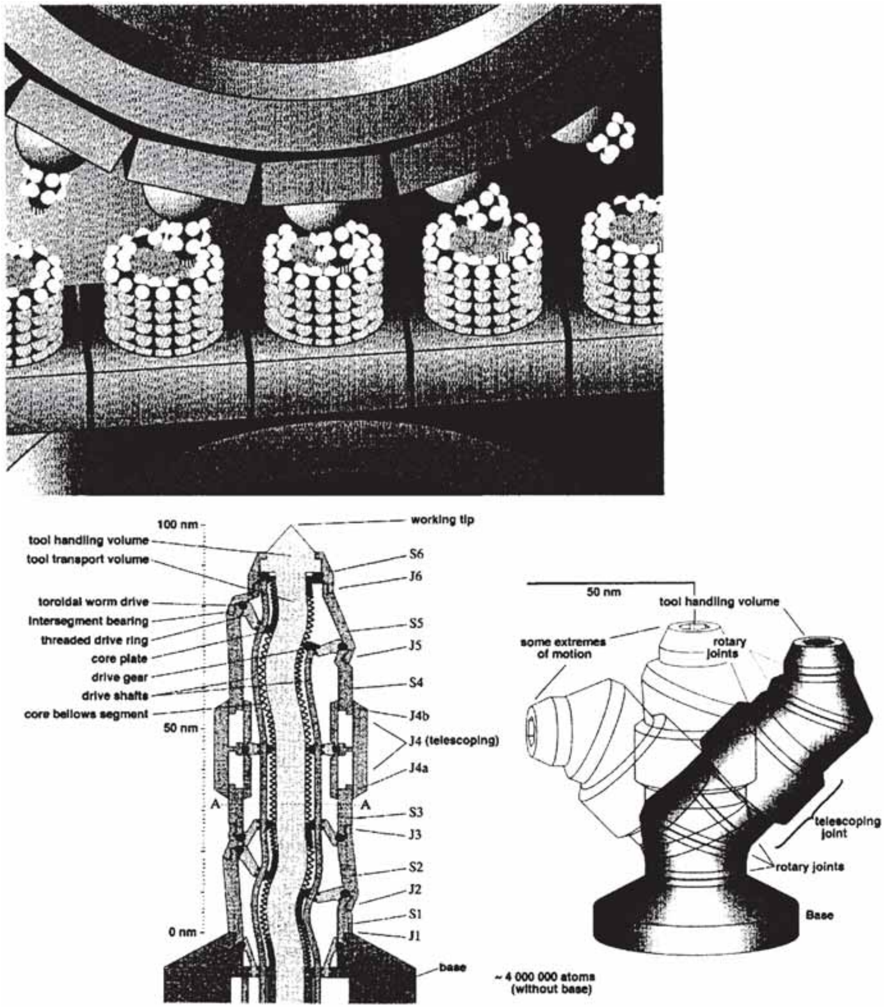


Figure 2. Molecular mills and molecular positioners. Molecular mills (top) would be used for high speed fabrication of highly redundant components. In this illustration a hydrogen atom (striped) is being added to a sleeve bearing as it passes by on a conveyor (which is not drawn to atomic detail). Molecular positioning arms (bottom) would be used to fabricate more customized components. At the nanoscale, megahertz rates of atomic placement are typical and estimates of system performance show that a four million atom manipulator arm (top) could make a copy of itself in less than 10 seconds. This is consistent with the known molecular processing speeds of enzymes in biological systems. *Sources: K.E. Drexler, Nanosystems [5], and Institute for Molecular Manufacturing (www.imm.org).*

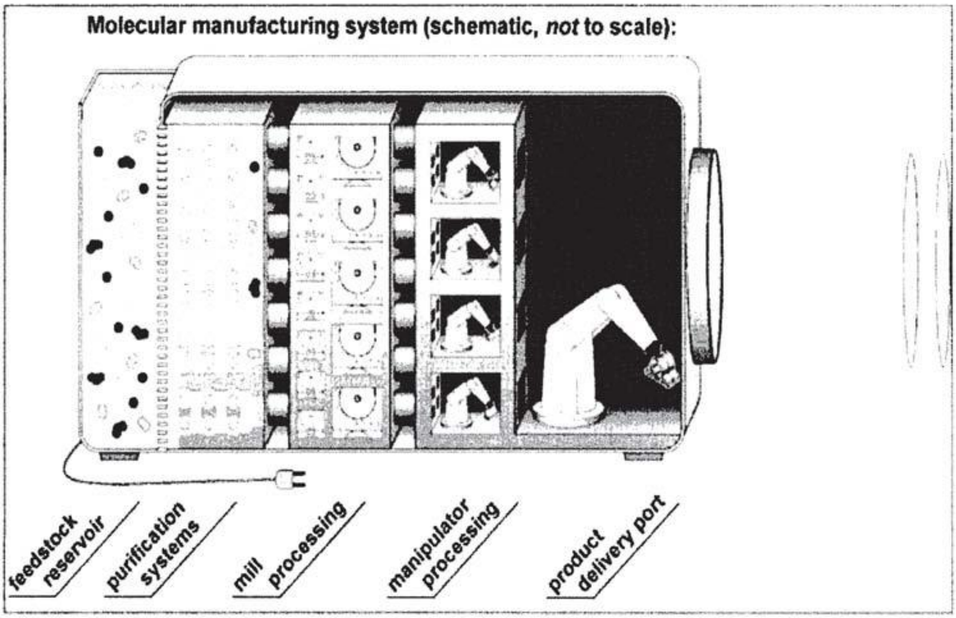


Figure 3. The desktop assembler concept. An exemplar 1 kg desktop assembler would produce atomically exact products at a rate of 1 kg/hr, would have a waste product of 1.5 kg/hr of high purity water, and generate 3.6 kW/hr excess power along with 1.1 kW/hr of waste heat (from the release of energy from breaking bonds of inexpensive feedstock molecules). One product of the desktop assembler would be a copy of itself, but the system could be reprogrammed to synthesize other items such as food, clothing, or computers. *Source: Institute for Molecular Manufacturing (www.imm.org).*

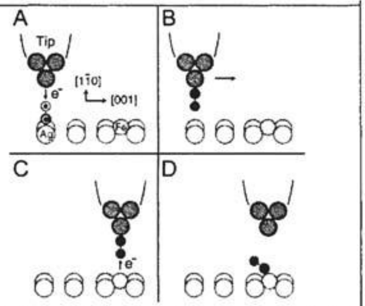
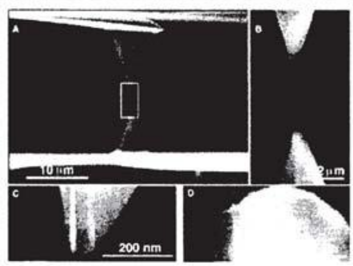
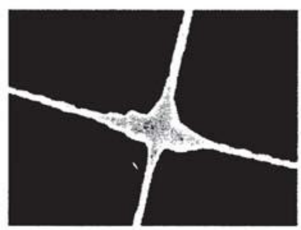
STATE OF THE ART

In recent years there have been significant theoretical and experimental advances in molecular technologies that are enabling the development molecular manufacturing. Here, we focus on key experimental advances, which are summarized in Tables 1–3. Table 1 provides examples of advances in molecular construction. In 1999 Ho and Lee achieved the first documented instance of positional molecular assembly in a non-biological system, when they picked up a single molecule of carbon monoxide, positioned it over a single atom of iron, and applied a voltage to force a chemical bond to occur between the Fe and CO. Ruoff and Banhart employed electron beams to bind carbon nanotubes to each other and to an atomic force microscope tip, demonstrating a successful joining technique.

Table 2 lists some advances in molecular electronic device development. The 1991 discovery of the carbon nanotube, and subsequent investigations that revealed its novel electronic properties, provided the groundwork for the stunning achievement of the demonstration of a molecular electronic memory based on carbon nanotubes in 2001 by Stan William's group at Hewlett Packard.

Molecular motors are ubiquitous in biological systems (for example, bacterial flagella, or the actin/myosin in our own muscle tissue). Table 3 provides examples showing that we can co-opt a biological motor and attach it to inorganic devices (Montemagno), and create a fully synthetic molecular motor based on a nested carbon nanotube bearing (Zettl). Nested carbon nanotubes can also serve as a telescoping arm; Van der Vaals forces provide a restoring force that cause an extended tube to retreat back to its original position.

Table 1. Experimental Advances in Molecular Construction

1999	Ho and Lee (Cornell U.) used a scanning tunneling microscope to pick up a single carbon monoxide molecule and chemically bind it to a single iron atom by applying a voltage [7] (see picture, right). This proved the concept of positional assembly using a non-biological robotic system.	
2000	Ruoff's group (Northwestern U.) used an electron beam to attach individual nanotubes to cantilevers, then measured their tensile strength (up to 63 GPa) [8].	
2001	Banhart's group (U. of Ulm, Germany) used an electron beam to attach individual nanotubes to each other [9].	

Research Initiatives in the US. In 1993 Rice University announced the first laboratory in the U.S. dedicated to nanotechnology research, and since then several dozen institutions worldwide have established their own dedicated centers. In 1996 Jim Von Ehr formed Zyvex, the first molecular nanotechnology company. Their goal is to develop the technology and build self-replicating molecular assemblers. Other nanotechnology companies have since been established (or divisions created within larger companies), many focused on (1) molecular electronic devices for computer applications, (2) the synthesis of carbon nanotubes and other fullerenes, and (3) the synthesis of inorganic nanoparticles. In 2000, President Clinton announced the National Nanotechnology Initiative (NNI) with a doubling of funding on nanotechnology research to about \$500 million annually. This move cemented the already growing interest in nanotechnology in the United States, and there are similar new initiatives in Europe, Japan, and China. The NNI FY2004 funding level is \$847M.

Table 2. Experimental Advances in Molecular Electronic Devices

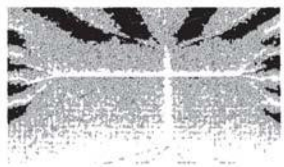
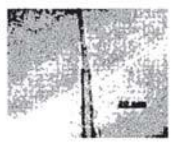
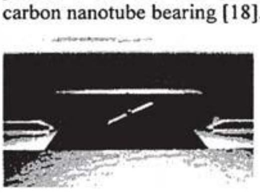
1996	The first conductivity measurements of single molecules using an STM [10].	
1997	• The first measurement of electronic conduction in a single molecular wire [11]. • The electrical conductivity of carbon nanotubes was demonstrated. • The first molecular diodes were synthesized [12, 13].	
1998	Carbon nanotube transistors were made and characterized.	
1999	Reversible molecular switches were synthesized and tested (Hewlett Packard/UCLA, Yale/Rice)	
2001	Stan Williams' group at Hewlett Packard demonstrated a 64-bit molecular electronic memory [14].	
2004	Target year for completion of a DARPA-funded 16 kilobit molecular electronic memory (10^{11} bits/cm^2), now under development [15].	

Table 3. Experimental Advances in Molecular Electromechanical Devices

1999	Carlo Montemagno and George Bachand (Cornell) created the first organic/inorganic integrated molecular motor, using a molecule of the enzyme ATPase coupled to a metallic substrate with a genetically engineered handle. [16]	
2001	Alex Zettl's group at Lawrence Berkeley Laboratories developed a nearly frictionless cylindrical molecular bearing (that can also serve as a telescoping arm) based on nested carbon nanotubes [17].	 
2003	Alex Zettl's group at UC Berkeley developed an electrostatic motor using electron beam lithography to pattern a 100-300 nm gold rotor suspended with a carbon nanotube bearing [18]. 	

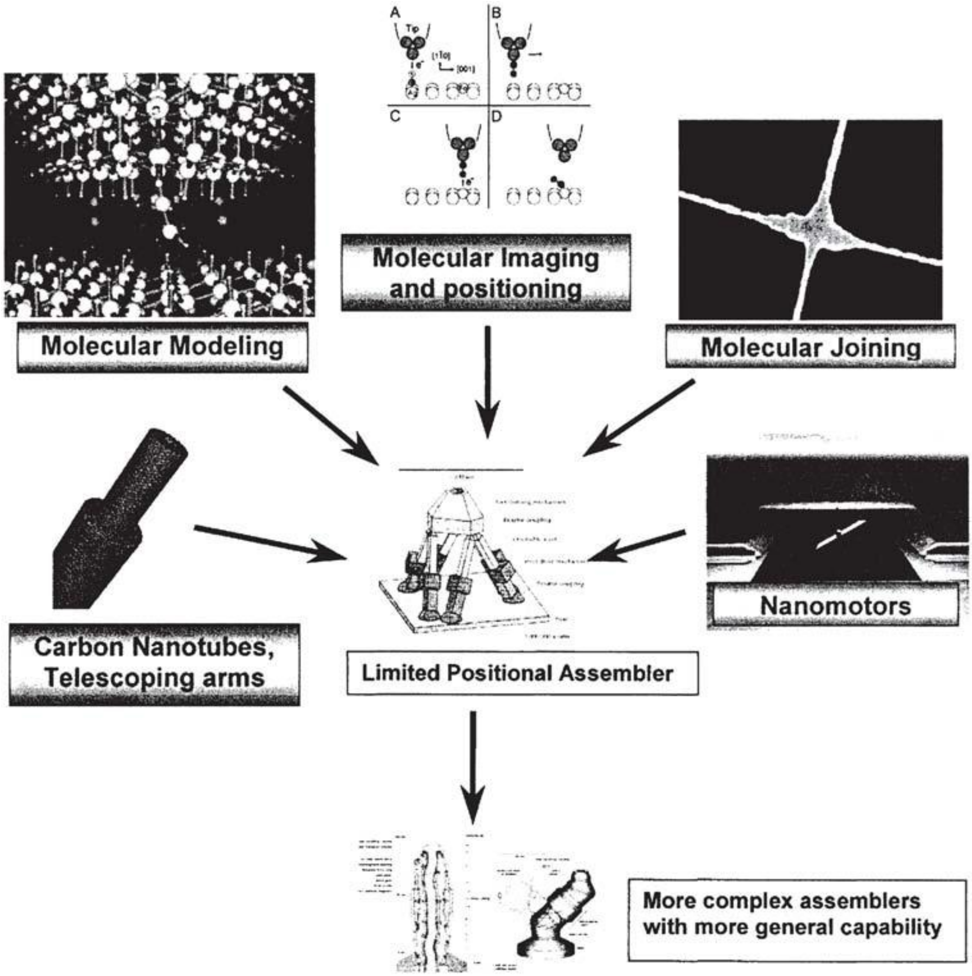


Figure 4. An illustration of the technological advances that are leading to the development of molecular robotic positioning systems.

Figure 4 summarizes recent advances in molecular technologies that have now provided many of the building blocks and construction methods needed to build a positional assembler: structural members, sliding and rotating parts, motors, and positioning and joining technology. Carbon nanotubes, which have been commercially available for several years, can serve as strong, stiff, structural members. They can be joined with electron beams. Individual molecules can be positioned and joined to structures with a scanning tunneling microscope. Nested carbon nanotubes can serve as both cylindrical bearings and telescoping arms. An electrostatic nanomotor has also been created and tested. Molecular modeling techniques can be used to analyze designs prior to construction, further speeding the development process. Crude, less capable assemblers, coupled with continuing advances to make molecular electromechanical components, would lead to more highly advanced molecular assembler systems with broader capabilities.

TIMEFRAME

Molecular manufacturing R&D, and indeed *all* technological progress, is proceeding at an accelerating pace. This has been quantified by Ray Kurzweil, who has shown that the *rate* doubles every decade [19]. In the next ten years we will perform the equivalent of twenty years worth of research at today's rate of progress, and the next century will see the equivalent of 20,000 years of progress (measured against today's rate). Double exponential growth curves are not intuitive, rendering even the best timeframe guesses by leading experts wrong by orders of magnitude. We can avoid these guesswork errors to some extent by focusing on trendlines for several technologies related to the one of interest. Trendlines for rates of advance in the distinct fields of precision machining and microlithography point to the mass production of atomically exact mechanical structures and computer chips around the year 2015 [20, 21]; Kurzweil's trendline (Figure 5, below) includes the advent of molecular mechanical devices a few years ago. Given (a) the trendlines for electronic and mechanical devices, (b) the current state of the art, especially the fact that the first robotically-controlled positional molecular assembly was demonstrated in 1999, and (c) these more general increasing rates of advance, the Institute for Molecular Manufacturing projects that a molecular assembler could be constructed by 2015.

Barriers to Progress. Despite promises of an economic revolution, and continuing successes in developing molecular robotic components, there are no large scale programs to develop molecular assembler systems. Part of the reason for this has been an ongoing debate in the U.S. about the feasibility of molecular assembly [22, 23], in which the basis for the technology has been brought into question. This may have been exacerbated by Bill Joy's *Wired* article, "Why the future doesn't need us," [24] in which he advocated ceasing research on molecular nanotechnology because of its potential dangers. Threatened with the spectre of losses in funding for all nanotechnology-related research, it was easier to deny the technology completely and marginalize Bill Joy than to clarify the distinctions between various kinds of nanotechnology research and address any dangers directly. European nations seem less concerned about this controversy. For example, in its market analysis Deutsche Bank AG identified molecular manufacturing as one of only three areas of high growth development in nanotechnology [25].

One concern about the ramifications of this debate is that, although development will progress with or without an integrated approach to developing molecular assembler systems, needed safeguards may be omitted without a concomitant focus on proper systems engineering.

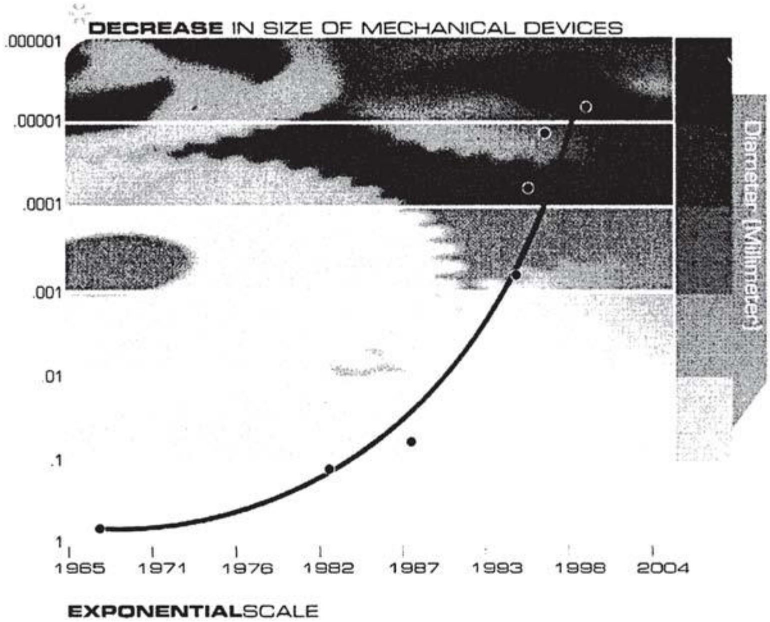


Figure 5. The double exponential decrease in the size of mechanical devices over time (scale is in millimeters). The advent of molecular mechanical devices occurred roughly where the curves intersects 10^{-5}mm (or 10nm—the diameter of a nested carbon nanotube). *Illustration courtesy Ray Kurzweil, KurrweilAI.net.*

IMPLICATIONS FOR TEXTILES

There are clear advantages to having materials that are 100 times stronger than we have now. Objects made from these materials could be up to 100 times lighter, using 100 times less material. As a result, ultralight cars, trucks, trains, and planes would use far less energy, especially with atomically smooth surfaces on moving parts and aerodynamic surfaces to reduce internal friction and air resistance losses.

Textiles will have similar gains in performance. Today, basic units of fabrics are molecules of natural and synthetic materials such as cotton (cellulose), wool (α-keratins), rayon (cellulose), and polyester. Bundles of these molecules are twisted to form fibers, which can be spun into threads and yarns. An obvious way to strengthen these conventional materials would be to reinforce them with carbon nanotubes—the current darling of nanotechnology materials. In fact there are already intensive efforts by groups around the world to create fibers from carbon nanotubes, which individually have a tensile strength of about 100 GPa. This is more than 50 times stronger than a typical steel and 1/3 the density. By comparison, commercial rayon has a tensile strength of 0.45 GPa and nylon, 0.5–0.8 GPa.

One of the difficulties in using carbon nanotubes in textiles is that it is difficult to grow nanotube molecules into centimeter lengths without loss of strength (due to processing-induced defects in long molecules). It's also difficult to twist shorter nanotubes into a fiber while maintaining the high strength of the individual nanotube. With molecular manufacturing, arbitrarily long nanotubes would be possible, and textiles could be fabricated to nearly their theoretical strengths.

Carbon nanotubes also have a high thermal conductivity along the axis (about three times that of diamond, and 15 times that of copper). Like diamond, carbon nanotubes are very stable in air to 1000°C. With these properties, a carbon-nanotube-based textile would make an excellent heat resistant fabric. The high axial thermal conductivity would act as a natural heat pipe to help to dissipate energy from hot spots on the material. Thermal conductivity could be quite low in the transverse plane with an open array of molecules with long, widely spaced cross-links.

Today's textile materials made with molecular manufacturing would be considerably stronger. The theoretical strength of cellulose is 12–19 GPa, so the strength of cotton and rayon could be improved more than ten-fold with molecular manufacturing. As Roger Soderberg has pointed out, there would be virtually 100% efficiency in converting yarns to fabric tensile strength due to the high level of uniformity in both strength and elongation from one yarn to another [26]. Fiber separation could be eliminated as a failure mode by connecting individual fibers end to end and making them continuous, but still bundled and twisted in the same amorphous way. It seems possible to do this while maintaining the look and feel of current fabrics, if desired.

Smart materials and nanotechnology

While synthesis of defect-free materials will lead to substantial improvements in performance, molecular nanotechnology will make more radical changes possible by integrating computers, sensors, and micro- and nanomachines with materials. Here are some ideas:

- Micropumps and flexible microtubes could transport coolant or a heated medium to needed parts of clothing.

- The kinds of sorting rotors shown in Figure 1 could be arrayed as "pores" in a semi-permeable membrane to allow only particular kinds of molecules through. Water might be a useful molecule to select for, to keep one side of a fabric dry or another side wet. On the wet side, the water could be transported away to an evaporator, or stored.

- *Active, programmable materials.* A rich integration of sensors, computers, and actuators within structural materials will blur the distinction between materials and machines, allowing the design and construction of objects that can be programmably reconfigured to sub-micron precision. These materials could monitor and report on their own state of "health." Figure 6 illustrates this concept with a latticework of machines linked by telescoping, interlocking arms. Both information and power would be transmitted through the arms to the individually addressable nodes. By selecting which screws would tighten and which would loosen, the shape of a item could change to conform to the needs of the user. A solid, rigid object could be made to behave like a fabric by effecting rapid changes in its shape, or with temporary disconnections between some cells. A flexible fabric could turn rigid by having loosely bound cells connect into a stiff framework. Thus, distinctions between fabrics and other types of rigid materials could blur.

The programmable material concept is not limited to fabrics but has many potential applications there. One example that Drexler pointed out would be a space suit that would allow nearly as much freedom of movement as one's own skin. Imbedded computers connected to strain gages could sense the wearer's intended movement and adjust the material accordingly. Reflectance of the outer layer could be variable to absorb needed amounts of heat from the sun-facing side and transport it to cold spots—although the material's insulative properties would allow very little of the wearer's heat to escape. Excess heat could be transported to radiators on the cold side.

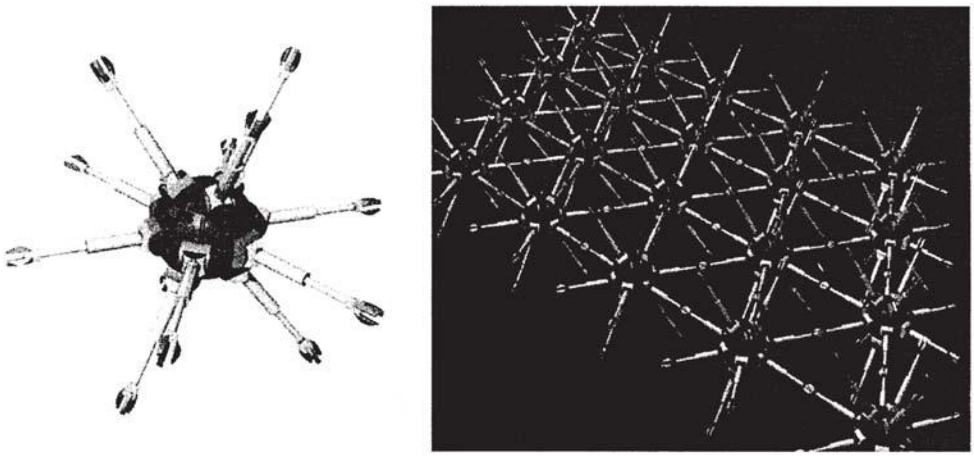


Figure 6. An individual node (left) and a 2D array of interlocked nodes (right). Materials made from these devices could be instructed to change their shape in rapid fashion. *Illustration by J.Storrs Hall, Institute for Molecular Manufacturing.*

- Fabrics could be self-cleaning: robotic devices similar to mites could periodically scour the fabric surfaces and integral conveyors could transport the dirt to a collection site, or the previously mentioned molecule-selective membrane could transport water to one side or the other for a cleaning rinse.

- Fabrics could be self-repairing: sensors would detect discontinuities in the material via loss of signal or a reported strain overload and send robotic "crews" to repair the damage. Self-shaping fabrics would be able to return to their original shape around a tear until repairs are effected.

- Large sections of fabrics could be made without visible seams by joining panels of fabric with microscopic mechanical couplings along their edges. Similarly, surfaces could contain mechanical couplings that, when pressed together would bond with nearly the strength of the bulk material. This 'smart velcro' could latch and unlatch at the user's request.

SUMMARY

Molecular manufacturing is an emerging technology that is being developed to build large objects to atomic precision, quickly and cheaply, with virtually no defects. In recent years, molecular manufacturing has progressed from theoretical studies to the construction of working molecular machine components. Positional molecular assembly has been demonstrated in the laboratory, and a potentially useful artificial molecular motor has been synthesized and tested. One company, Zyvex, has announced its intention to design and build a molecular assembler, and many companies are designing and building molecular computer components. Molecular transistors have been built and tested, and a working molecular electronic memory unit has been demonstrated.

Much work remains before molecular robots begin assembling machine components, ushering in the era of molecular manufacturing. But when molecular manufacturing matures, probably by the year 2015, it promises to be an inexpensive, energy efficient, and environmentally benign way to make a new generation of advanced textiles.

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THE SUBSTITUTION OF HEMP AND FLAX FOR COTTON IN WOUND SPOOL FILTERS

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INTRODUCTION

Cartridge filters are used in applications where the prime concern is to maintain a clean fluid rather than to recover solids[1]. They feature high efficiency but relatively low capacity to hold solids[2]. The objective of this paper is to investigate the possibility of producing cartridge filters developed using natural hemp and flax fibre and comparing the performance of prototype cartridges to the filtration performance of cartridge filters constructed from cotton. This has lead to the development of new cartridge filters constructed from hemp and flax fibres for the solid-liquid fluid clarification market. The aim would be to replace imported cotton with UK hemp and flax fibres as the raw material for the manufacture of cartridge filters. The fibres produced by these plants have been chosen because they are vegetable fibres that are cellulosic in composition, have properties that are similar to cotton making them an attractive substitute and they require less intensive farming methods rendering them more environmentally sustainable.

RAW MATERIAL

Cotton

Cotton has been the most popular fibre since the beginning of times. No other fibre comes close to duplicating all of the desirable characteristics combined in cotton. Physically the individual cotton fibre consists of a single long cell, with one end attached directly to the surface of the seed. From the field, the seed cotton is sent for the separation of lint and seed. The cotton first goes through dryers to reduce moisture content and then through cleaning equipment to remove foreign matter. The cotton is then air conveyed to gin stands where revolving circular saws pull the lint through closely spaced ribs that prevent the seed from passing through. The lint is removed from the saw teeth by air blasts or rotating brushes, and then compressed into bales. Lint from several bales is mixed and blended together to provide a uniform blend of fibre properties.

Hemp and Flax

Bast fibres possess by nature a high degree of variability. These fibres are constructed of long thick-walled cells which overlap one another; they are cemented together by non-cellulosic materials to form continuous strands that may run the entire length of plant stem. The strands of bast fibres are normally released from the cellular and woody tissue of the stem by a process of natural decomposition called retting (controlled rotting)[3]. This is the most important process in the preparation of the fibre. It consists essentially in submitting the straw to the action of water and allowing fermentation to take place. The connection between the bast fibres and the woody core is loosened by micro organisms after adding appropriate amount of water. As a result, the bast fibre is separated from the core of the plant, the connection between different parts of the plant is loosened. Once the retting process is complete the retted stalks are dried before it is subjected to the breaking process where the aim is to separate as much as possible the flexible fibre part and the solid core portion of the plant in a sequence of squeeze, break and scutching processes. By using rollers, the decorticated fibres are made softer.

Two traditional methods used to ret hemp and flax are water and dew retting. In water retting, the stems are submerged in rivers and lakes, and anaerobic bacteria colonize the stems and degrade pectins and other matrix compounds, freeing fibres from the core tissues. Dew retting depends on the removal of matrix materials from the cellulosic fibres before cellulolysis, which causes the weaking of the fibres. Water retting results in high quality fibre but has been discontinued in western countries because of the extensive stench and pollution from the fermentation products. Dew retting produces coarser and lower quality fibres with poor consistency in fibre characteristics than water retting[4]. Because of problems with both water and dew retting, extensive research is being carried out to develop enzymatic and mechanical retting to produce fine staple equivalent to cotton.

YARN FORMATION

Spinning converts a mass of short fibres into yarns which requires a number of stages. Initially the staple fibres undergo carding in which they are disentangled, straightened into length-wise alignment and any impurities are removed to produce card sliver. After carding, several slivers are combined. The sliver is then put through an additional straightening called combing. The combing process forms a comb of sliver which in turn produces a smoother and more even yarn before undergoing the drawing process. Drawing produces long thin slivers which are twisted and wound onto bobbins. After drawing, the fibres are spun using a spinning system specific to the end use of the yarn[5]. There is an extensive range of different spinning systems. Important aspects of any spinning system are the fibre types that can be spun, the count range, the economics of the process and the suitability of the resulting yarn structure to a wide range of end users. In the spinning process, there is always a fixed relation between the weight of the original quantity of fibre and the length of yarn produced from that amount of raw material. This relation indicates the thickness of the yarn.

The cotton yarn used is spun using the open-end spinning system, more specifically friction spinning where the free end of the yarn is rotated while individual fibres are collected and twisted onto the end to increase the yarn length. The fibre deposition does not result in a straight and parallel arrangement of the fibres in the spun yarn. As a result it is only suitable for very open coarse count yarn[6]. The conventional ring spinning technique is used to form the hemp and flax yarns, the main reason being the suitability of this technique to produce the required yarn structure. The ring spinning technique is effectively a twisting and winding mechanism where the ring spinning frame completes the manufacture of yarn by drawing out the roving, inserting twist and by winding the yarn onto a large bobbin forming what is referred to as a cheese.

NATURAL FIBRES

When considering the use of natural fibres for filtration purposes the important factors to consider are the fibre properties, both mechanical and chemical properties, fibre dimensions, fibre density and the manufactured yarn properties. Desirable properties are that the fibre length should not be shorter than 6–12 mm and that the fibre length should be several hundred times the width to give a high L/D ratio. These two conditions are important. The absence of either would not allow the fibre to hold together which would not allow fibres to be twisted together to form a yarn[3]. The fineness of the fibre, which is dependent on the width of the fibre, enables the determination of how fine a yarn can be produced. Table 1 gives the dimensions of the three chosen fibres. There is a large variation in fibre dimension as it is an inherited characteristic that can be greatly influenced by soil and weather[7].

Table 1. Dimensions of fibres[7,8]

Dimensions	Length,	Width, mm	Fineness, µm		L/D
Fibres	Range	Average	Minimum	Maximum	Ratio
Cotton	1.5-5.6	0.012-0.025	2.82	8.46	2500
Hemp	100-300	0.06-9.04	8.46	56.4	1078
Flax	20-140	0.04-0.62	5.64	45.1	1778

CHEMICAL PROPERTIES

Natural fibres of vegetable origin are constituted of cellulose with varying amounts of other natural substances such as lignin, pectin, hemicellulose, waxes and gums[8]. The amount of these associated substances and the ease with which the cellulose fibre can be separated from them determine how useful the fibre can be[3]. Hemp and flax are lignocellulosic fibres where the cell wall is made up mainly cellulose, hemicellulose and lignin. Cotton is a non-lignocellulosic fibre that does not contain lignin. Cellulose is the basic structural component of plant fibres and has a molecular weight>10^6 g/mole[9]. It is the most important organic compound produced by plants. The cellulose molecules consists of glucose units linked together in long chains, which in turn are linked together in bundles called micro fibrils. The structure of cellulose is shown in Figure 1[9]. Cellulose molecules run parallel to one another and forms spiral that are highly parallel to one another in vegetable fibres. Flax and hemp contain a lower percent of cellulose than cotton and the spiral angle of the cellulose is lower than that of cotton. A lower helix angle increases the stiffness of the fibre, accounts for low extensibility and makes the fibre brittle[7].

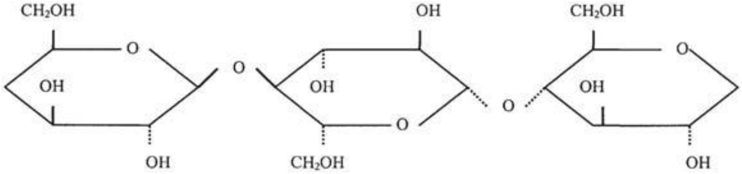

Figure 1. Chemical structure of cellulose

Hemicelluloses are also found in all plant fibres. Hemicelluloses are polysaccharides bonded together in relatively short, branching chains. They are intimately associated with the cellulose microfibrils, embedding the cellulose in a matrix. Hemicelluloses are very hydrophilic. Lignin, the Latin word for wood, is the compound which gives rigidity to the plant[10]. The chemical composition of the three fibres are given in Table 2[7].

Table 2. Chemical composition of fibres[11,12]

Fibres	Cellulose	Hemi-cellulose	Pectin	Lignin	Extractives
Cotton	91.8	6.4		0	1.8
Hemp	74.4	17.9	0.9	3.7	3.1
Flax	71.2	18.6	2.0	2.2	6.0

MECHANICAL PROPERTIES

Yarns are built up by twisting together the long, thin flexible but strong things called fibres therefore the properties of the yarn depends very largely on the properties of the fibres from which it is made[3]. Strength is needed to enable the fibres to withstand the spinning process and to provide strength in the final yarn. Flexibility permits the fibres to be spun. Flax is a stronger fibre than cotton. It is a particularly inextensible fibre and it stretches only slightly as tension increases. It has a high degree of rigidity and resists bending. Hemp is a coarser fibre than flax. The fibre is strong and durable more lignified than flax and is consequently stiffer. Certain mechanical properties of the three fibres are shown in Table 3.

Table 3. Mechanical properties of fibres[3,9,11,12]

Fibres	Density (g/m^3)	Ultimate strain at break (%)	Tensile strength (g/dtex)	Moisture adsorption (%)	Spirality	Spiral angle (^{0})
Cotton	1.52	5-10	3-6	8	Z	20-30
Hemp	1.48	2-4	5-6	8	Z	5-10
Flax	1.51	2-7	5-6	7	S	5-10

STRUCTURE AND APPEARANCE

The surface structure of a fibre is most important in that it controls the behaviour of the fibres in the yarn. The cross-sectional shape of a fibre has an important influence on its behaviour in a yarn. Cotton has a flat, ribbon-like cross section. Figure 2 shows that when viewed under the microscope the cotton fibre appears to be twisted frequently along its entire length with the direction of the twist reversing occasionally. Twists are referred to as convolutions and it is believed that they are important in spinning because they contribute to the natural interlocking of the fibres in the yarn, enabling the fibres to grip to one another when spun[7].

Figure 2. Cotton fibre SEM

In Figure 3 the hemp fibres are seen to be irregular in shape, being flattened at some points along its length but cylindrical at others with joints, crack, swelling and other irregularities on the surface[3]. There are striations on the surface of the fibre but no nodes like those found in flax[13].

Flax is polygonal in cross-section. Seen under the microscope in Figure 4, the fibre cells show up as long cylindrical tubes which may be smooth or striated lengthwise. They do not have convolutions which are characteristic of cotton. The width of the fibre may vary several times along its length. There are swellings or 'nodes' at many points and the fibres show characteristic cross-markings[3].

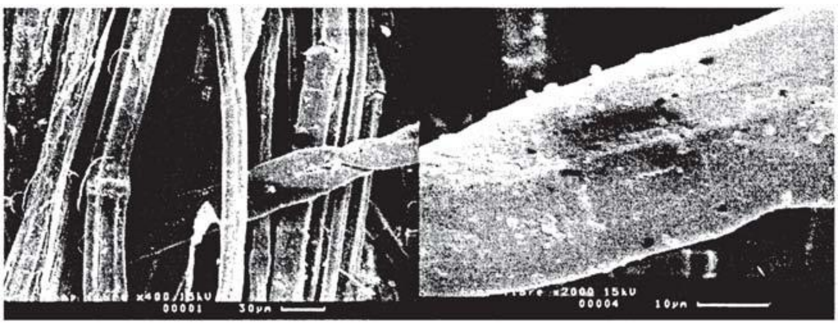

Figure 3. Hemp fibre SEM

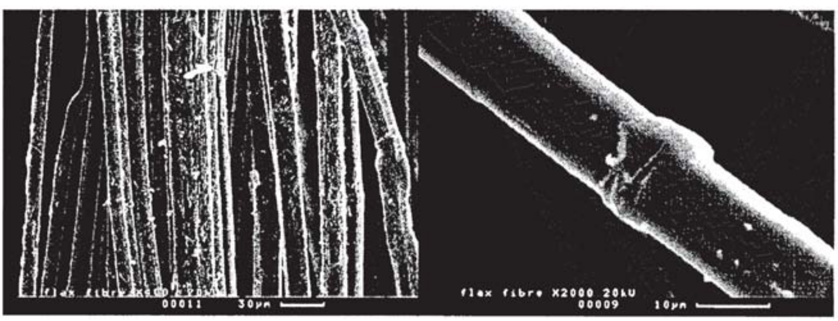

Figure 4. Flax fibre SEM

ENVIRONMENTAL BENEFITS

The farming of cotton requires the use of large volumes of agrochemicals to provide protection against pests and also large volumes of irrigation water to maximise fibre yields. Both these requirements have damaging effects on the environment. Hemp and flax have considerably less requirements for intensive agricultural intervention and almost zero requirements for fertilisers and pesticides. Hemp and flax are also useful break crops being beneficial in crop rotation and are sustainable. And the biomass production of these plants recycles CO_2, cleaning the atmosphere.

CARTRIDGE FILTER FABRICATION

Spool-wound cartridge filters are constructed from a length of yarn that is wound around a central perforated core. The yarn consists of intertwined fibres of 15–20 μm in diameter, the fibre diameter being important in determining the particle retention efficiency of the final product. This yarn is teased to produce a nap and wound around the core in a precisely controlled winding pattern. A diamond pattern is the most common configuration used. This creates a graded pore structure which decreases in size from outer, upstream surface to the inner central core. Proper brushing of the yarn provides a high surface area for adsorptive filtration as well as tortuous flow channels for particle interception. The performance of a filter depends upon the type of fibre and the way the yarn is produced and wound[2]. In addition factors such as fibre diameter and length, yarn diameter, tension and winding technique all effect the flow path, shape and size, as well as the amount and nature of internal surfaces available for particle collection. Such characteristics can be varied throughout the depth of the filter medium.

DEVELOPMENT IN STANDARDISED FILTER TESTING

The test rig designed for this work is shown in Figure 5. The test system is a modified single-pass version of the test system described in ISO 4572 (1981)[14]. ISO 4572 describes the multipass test system that has become accepted as the most reliable and comprehensive filter test method currently available. In a multi-pass test a fluid containing a known quantity of particulate contaminant is continuously circulated through the filter under test. Fresh contaminant is continuously fed into the system in order to replace what has been removed from the fluid by the filter. Samples of the influent and effluent streams are continuously collected and analysed in order to determine the number and size of particles in the test fluids, from which the particle removal efficiency (%) of the filter may be calculated. In addition, this test also provides information on filter element life, dirt holding capacity and pressure tolerance. The modified test system utilises a very high efficiency clean-up filter that removes any particles remaining in the process fluid after passage through the test filter. This mode of testing represents the most frequent conditions of use of cartridge filters in real applications[9]. A further modification to the test system is the use of alternate upstream particle concentrations of 25 mg/l for 30 minutes and 3 mg/l for 30 minutes. This test, enables a single cartridge filter test to be conducted in a practical period of time and provides useful data on the performance of the filter during periods of both high and low upstream particle concentrations.

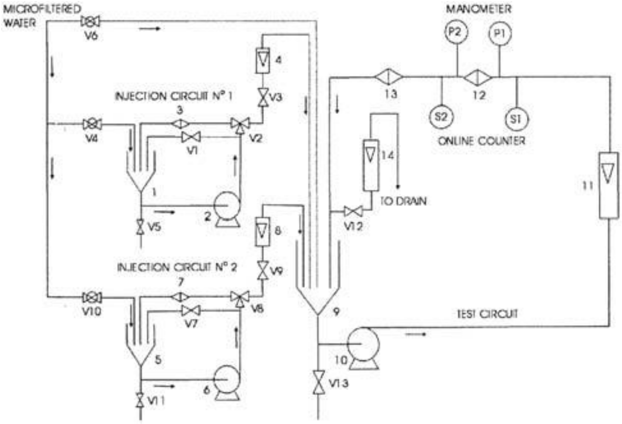

Figure 5. Design of the filter test system showing the injection circuit reservoirs (1,5), dosing pump (2,6), Clean up filters (3,7,13), dosing flow meter (4,8), test circuit reservoir (9), metering pump (10), test flow meter (11), test filter (12), flow meter to drain (14), pressure ports (P1, P2), sampling probes (S1, S2), valves (V1-V13)

The filters are tested by using pre-filtered water as the test fluid at a constant temperature of 25°C and a flowrate of 16 l/min. A standardised test dust (ISO Medium Test Dust) with a particle size range between 0 to 120 µm is used at a upstream concentration of 3 mg/l. This particle concentration is maintained for 30 minutes after which point the contaminant slurry is fed from a separate reservoir providing an upstream concentration of 25 mg/l for 30 minutes. After this time the feed slurry is switched back to the first feed reservoir providing a particle concentration of 3 mg/l for 30 minutes and so on. This practice ensures that the filter will attain a terminal differential pressure at 2 bar at the completion of the test. The filtration efficiency of the filter is monitored throughout the test by measuring the number and size of particles in the fluid downstream of the filter throughout the test with a Liquilaz automatic particle size analyser (Particle Measuring Technique (GB) Ltd.) The same measurements are taken for the fluid upstream of the filter when the particle concentration in the upstream fluid is 3 mg/l, since the higher particle concentration will exceed the sensitivity of the particle size analysis equipment which is 15,000 particles/ml[10].

Standard filter performance tests were carried out using wound cartridge filters constructed from hemp and flax yarn and compared with filters produced from cotton. Cotton cartridge filters nominally rated at 1, 5, 10 and 20 micron were constructed using 1000 tex yarn. Hemp and flax filters were then made up by the same manufacturer based on the standard winding pattern used for cotton cartridge filters. For the purpose of this research several modifications were carried out. Firstly due to the natural physical properties of the bast fibers, i.e the fiber length and fiber diameter, the yarn was constructed using the conventional ring spinning system because of its ability to process most natural fibers for the majority of end uses.

COMPARISON OF SPOOL WOUND CARTRIDGE FILTERS

For this paper, identical cotton, hemp and flax filters constructed from 1000 tex yarn and nominally rated at 5 micron will be compared and contrasted. The first batch of hemp yarn produced was made to match the identical cotton yarn. Upon testing the filters constructed and after further investigation was carried out, it was discovered that where the cotton yarn was made up to have 80 turns per meter the hemp yarn was twisted 116 times per meter. This resulted in a tighter yarn configuration to the cotton yarn.

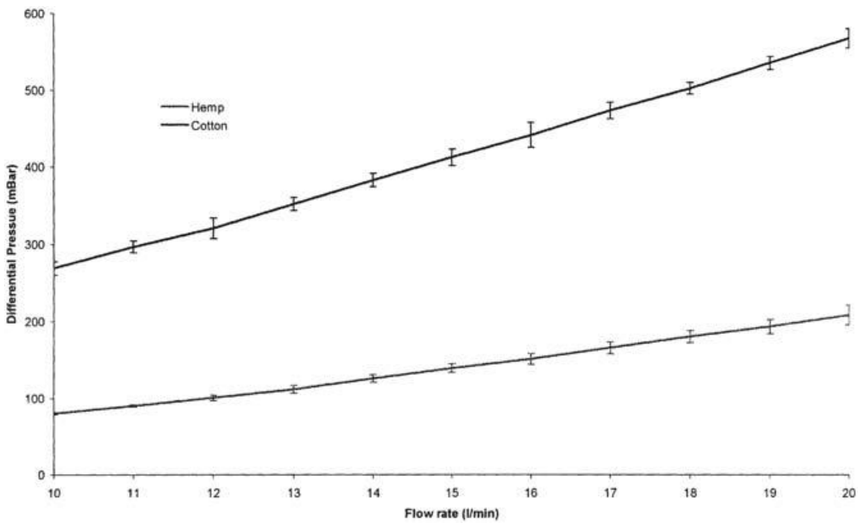

Figure 6. Clean element differential pressure of "5 micron" cotton (top line) and hemp filters (bottom line). Cotton yarn=80 turns/meter, hemp yarn=116 turns/meter.

The cotton and hemp clean element differential pressure is displayed in Figure 6. This differential pressure is also known as the initial head loss and corresponds to the resistance to fluid flow through the clean filter medium which is directly proportional to fluid velocity[15]. The cotton cartridge filter displays a considerable high clean element differential pressure which will result in a shorter element life when compared to the hemp filter. The higher clean pressure drop of the cotton filter is due to the nature of spinning system used to form the yarn. Friction spinning process results in a bulky yarn where the fibres are individually collected and twisted onto the yarn when compared to the ring spun yarn where the yarn is a collection of straight and parallel fibres twisted together which results in a neat yarn. Though the hemp filters were made up using the same production technique as the identical cotton filters, it is seen that the filters do not behave in a similar manner. As a result it will not be possible to give the same rating to the hemp filters as one would using the winding specifications used to construct the identical cotton filter.

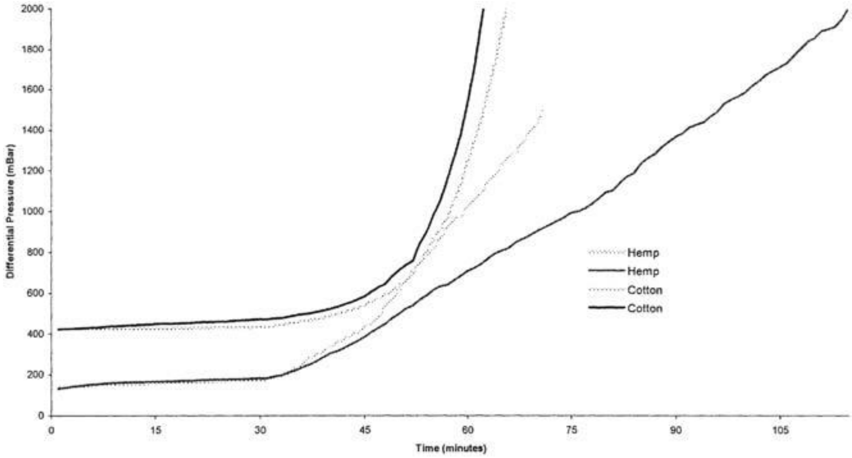

Figure 7. The element life of “5 micron” cotton (top solid and dashed curves) and hemp filters (bottom dashed and solid curves). Terminal pressure=2000 mBar, cotton yarn=80 turns/meter, hemp yarn=116 turns/meter.

The duration of the filter test in minutes is the time taken for the pressure differential across the test element to attain the terminal pressure differential. In this case the terminal pressure differential is defined at 2000 mBar. The change in pressure differential throughout element life as solids accumulated both on and within the filter structure is represented graphically in Figure 7. The cotton curve represents the classic life curve of a spool wound cartridge with little accumulation in the pressure differential throughout the majority of life until approximately 60% of the net pressure differential. At this point the increase in pressure differential in time is very rapid until attainment of the terminal pressure differential. The capacity of the filter is mostly consumed before the sharp increase in pressure differential. Hemp filters show an increase in pressure differently gradually. After the low concentration cycle for the first 30 minutes of its life the hemp cartridge displays a consistent accumulation in pressure differential throughout the entire duration of its life which results in the hemp cartridge having a longer element life than the cotton cartridge. A lower initial clean pressure drop displayed by the hemp cartridge in Figure 6 is a contributing factor to the longer element life until it reaches terminal differential pressure. The maximum allowable pressure tolerance of the filter is the limit beyond which the filter will fail structurally and must not be exceeded.

Analysis of the test fluid from upstream and downstream of the test element by the Liquilaz automatic particle size analyser allows the calculation of particle retention efficiency of the element which is displayed graphically in Figure 8 which demonstrates the variation in the retention of particles of different sizes. The particle retention efficiency is found to increase for larger sized particles. The element appears to become more efficient at retaining larger sized particles.

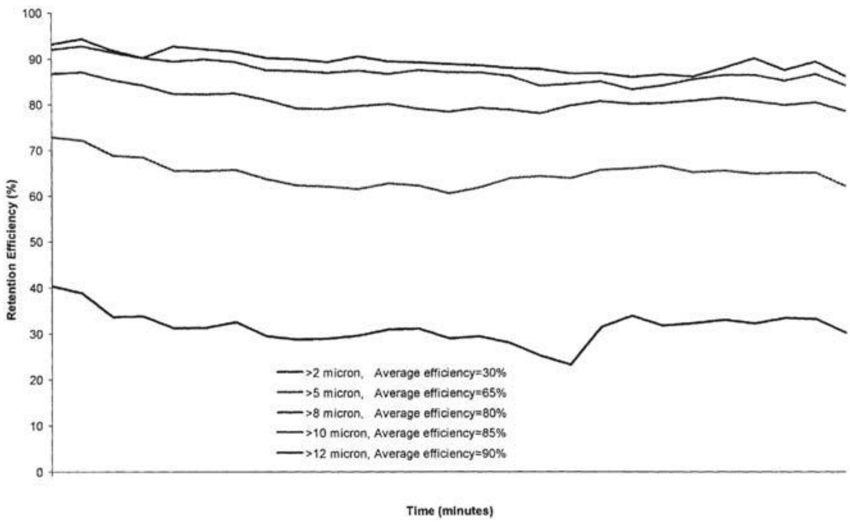

Figure 8. Retention efficiency of "5 micron" hemp filters (results shown in descending order, starting with >2 micron). Hemp yarn=116 turns/meter.

Upon comparison of the particle retention efficiencies attained by both the cotton and hemp filters tested it was seen that where the cotton filters displayed a retention efficiency of greater than 99% for all particles greater than 5 micron in size the identical hemp filter produced an efficiency of 65%. As these were the first production batch of the hemp filters, alterations to the yarn production and winding specifications is hoped to improve the performance even more. And as it was decided to initially concentrate on the hemp yarn and then use the information learnt to develop the flax yarn, latter modifications were applied in the production of the flax yarn as well. Though the cotton cartridges were wound using yarn having 1000 tex count, hemp and flax yarn were made to three different finesses, 1000, 800 and 500 tex. Ultimately this will allow initial comparison testing of cotton, hemp and flax cartridge filters of the same micron rating having the same yarn count which will provide a basis for changes in yarn count. The amount of twist applied to the production of the new hemp and flax yarn was made to match the cotton yarn having 80 turns per meter. Hemp and flax cartridges constructed from the modified yarn was tested and the results obtained analysed.

The clean element differential pressure of identical 5 micron cotton, hemp and flax filters constructed from 1000 tex yarn is displayed in Figure 9. Once again the cotton cartridges display a high clean element differential pressure while both the hemp and flax cartridges displayed a much lower differential pressure. Upon further investigation it was seen that the hemp cartridges initially constructed from the 1000 tex yarn with 116 turns per meter displayed a higher clean differential pressure to the cartridges constructed from the yarn modified to have a lower number of twist.

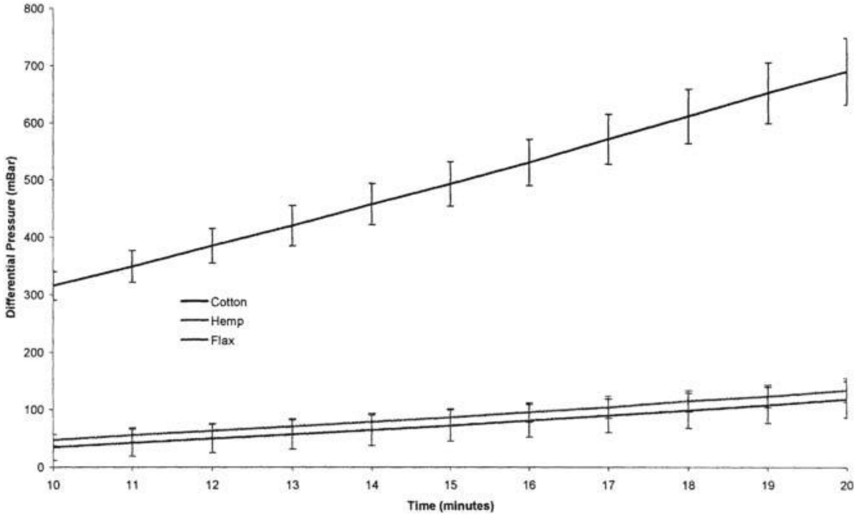

Figure 9. Clean element differential pressure of “5 micron” cotton (top line), hemp (middle line) and flax (bottom line) filters

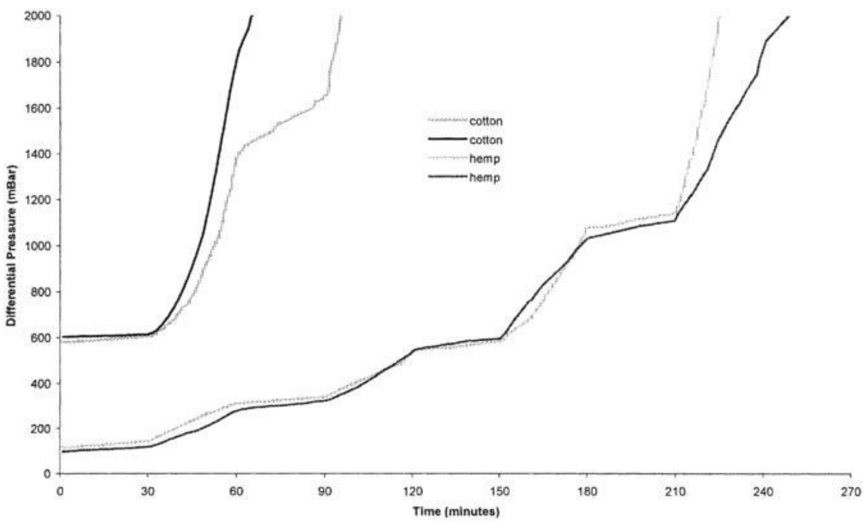

Figure 10. The element life of “5 micron” cotton (top two lines) and hemp (bottom two lines) filters (Terminal pressure=2000 Bar)

Figure 10 shows the increase in element life of the filters tested as particles accumulate in the filters pores. This figure enables us to visualise the speed of clogging which is a major element in the comparison of three cartridges when subjected to the same mass flow of solid particles. As shown previously the hemp filter elements exhibits a more continual accumulation in differential pressure when compared with cotton cartridges where the cotton filter curves are flat initially, becoming more steep towards the later stages of the test.

There are various characteristics that can be varied in the construction of a cartridge filter to provide a more efficient cartridge. Figure 11 shows the results of the latest developments to the cartridges compared to the standard cartridge. In the first instance the winding tension was varied, to construct cartridges with higher and looser winding tensions. Higher tensions give finer ratings, but also raises the pressure drop and drastically reduce filter life. Loose tension gives a coarser rating but makes the cartridge soft. Secondly the yarn was brushed. This gives a raised effect to provide a high surface area for filtration. Three different configurations of cartridges were tested, the first being heavy brushed and top tension cartridge, followed by heavy brushed and loose tension compared to the standard cartridge configuration.

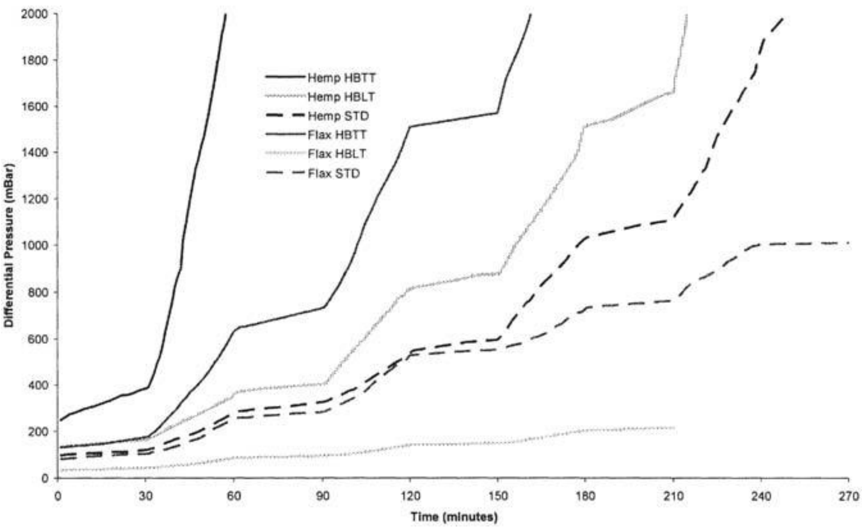

Figure 11. The element life of “5 micron” hemp and flax filters (Terminal pressure=2000 mBar, HBTT=heavy brushed, top tension, HBLT=heavy brushed, low tension, STD=standard winding)

Table 4. Average retention efficiencies of the “5 micron” hemp filters tested

Cartridge	>2 micron	>5 micron	>8 micron	>10	>12
Standard winding	46.67%	69.82%	82.28%	87.21%	87.16%
Heavy brushed, low tension	45.52%	68.59%	84.89%	90.28%	94.04%
Heavy brushed top tension	57.49%	78.21%	93.16%	97.86%	99.16%

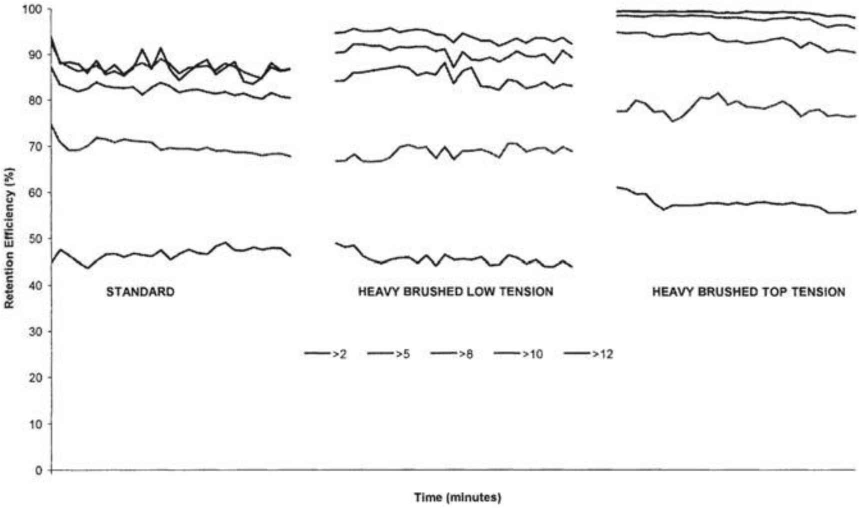

Figure 12. Retention efficiency of "5 micron" hemp filters of various modifications (results shown in descending order, starting with >2 micron)

The particle retention efficiencies of the various 5 micron hemp filters tested are displayed graphically in Figure 12 and the average retention efficiencies are given in Table 4. The heavy brushed cartridge with the higher tension displayed the highest capture efficiencies for all particle sizes while the heavy brushed loose tension and standard wound cartridges displayed similar capture efficiencies for particles sizes up to 8 micron after which the standard wound cartridge managed to retain the same percentage of particulate for particles greater than 10 micron while the particle removal efficiency displayed by heavy brushed, loose tension filter was found to increase for larger sized particles.

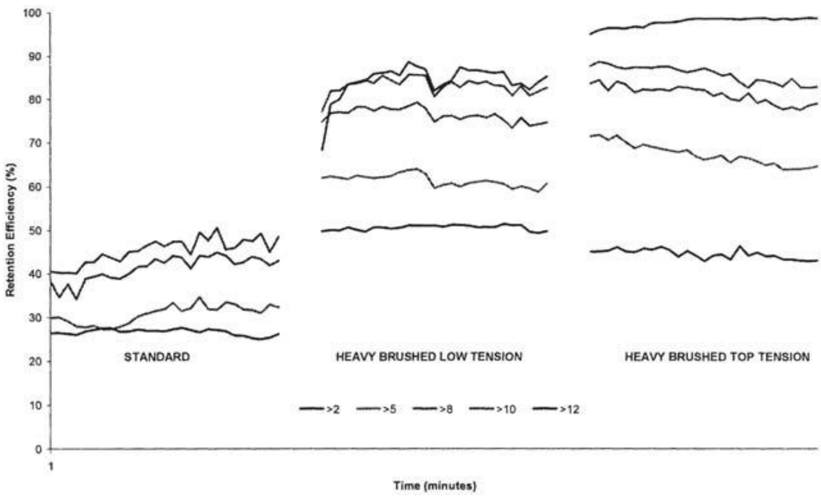

Figure 13. Retention efficiency of "5 micron" flax filters of various modifications (results shown in descending order, starting with >2 micron)

Table 5. Average retention efficiencies of the "5 micron" flax filters tested

Cartridge	>2 micron	>5 micron	>8 micron	>10	>12
Standard winding	26.66%	30.78%	41.24%	45.37%	ND
Heavy brushed, low tension	50.58%	61.39%	76.40%	83.11%	84.20%
Heavy brushed top tension	44.55%	67.38%	81.12%	85.83%	97.86%

The efficiencies of the various flax filters tested are displayed in Figure 13 and Table 5. Once again it is seen that the heavy brushed, tight tension cartridge displays the highest particulate capture efficiencies, followed by the heavy brushed, loose tension cartridge and finally the standard wound cartridge. Overall it is seen that the flax filters exhibit a lower retention efficiency that the identical hemp cartridge filters for all the particle sizes analysed.

The improved performance found when cotton filters were tested was attributed to the nature of the cotton fibres. The striated surface of the cotton fibres[7] and their ability to swell on interaction with water[2] ensures that the filter structure becomes tighter and less porous during filtration. The surface structure also facilitates the collection of particulate material in the ruffles along the surfaces of the fibres. This probably contributes to the accelerated accumulation in differential pressure even early in the life of cotton filters compared to hemp elements. Though the hemp fibre also shows characteristics of striations on its surface there are many other irregularities exhibited which include joints, cracks and swelling along its length which could present problems in particles attaching to its surface. The occurrence of dislocation or joints throughout the length of the flax fibre and its smooth surface when compared to the hemp fibre could be the reason for the reduced particulate capture efficiency displayed by the flax cartridges.

CONCLUSION

It can be said that the substitution of hemp and flax for cotton in spool wound cartridge filters has generated encouraging results. But in order to produce a competitive alternative to cotton and to use the multiple properties of the hemp and flax fibres the development or the application of processing methods is indispensable. Preparation and processing characteristics must be greatly improved to match bast fibres to those of cotton. The bast fibres and yarns used to construct the cartridges do not fulfil the requirements of the filtration industry. In regards to these wide distribution of fibre diameter and length the filtration industry is faced with vast processing problems. To enable an application of bast fibres, the advantages of the cotton fibre must be taken into account. For example, raw bast fibres can be shortened using a fibre cutting machine and sticky substances such as pectin and lignin must be removed and the fibres must be cottonized to gain almost complete isolation of single fibres such as those of cotton fibre[16].

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IT MAY BE ECO-FRIENDLY BUT IS AN INGEO ™/CELLULOSE BLEND STRONG ENOUGH TO WITHSTAND WET PROCESSING?

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ABSTRACT

The development of environmentally-sustainable poly (lactic acid) fibres, enable them to compete with conventional polyethylene terephthalate fibers. However, PLA fibers are more sensitive to wet processing treatments that PET fibers and this paper discusses how successful dyeing of this former may be achieved.

INTRODUCTION

Poly(lactic acid) (PLA) is a synthetic polyester derived from renewable sources such as corn. PLA has been used for many years in biomedical applications such as drug release systems, medical implants and surgical sutures because of its biodegradability and biocompatibility. It can be recycled either by re-melting or by hydrolysing into the starting monomer, lactic acid. Nowadays, apart from being used in medical applications, the versatility of PLA is exemplified by its use in packaging outlets as well as in a series of textile and agricultural applications [1,2]. As a consequence of its interesting properties and its potentially "green" credentials, PLA is being increasingly considered for use as a commodity polymer.

PLA fibres are expected to compete with petroleum-based materials both on a cost and performance basis, representing the first material to successfully bridge the gap between natural and synthetic fibres in its technical properties. Consequently, it has the potential to provide the textile industry with a novel product option, viz. an environmentally-friendly synthetic (polyester) polymer, which can be used in a range of apparel and non-apparel fabric applications [3,4]. Many of its properties are comparable to those of polyethylene terephthalate (PET) fibre e.g. its dimensional stability and crease resistance[3]. However, because it possesses superior moisture management properties, fabrics containing PLA are being considered for use in sportswear as well as other outerwear outlets. PLA fibres are marketed by Cargill Dow under the brand name INGEO and the work carried out at the University of Manchester has been done on samples of both fibres and fabrics supplied by Cargill Dow. Blends of PLA with both cotton and wool are also being investigated in order to produce higher value-added fabrics, which exhibit the combined characteristics of the individual fibres (dimensional stability and comfort).

Compared with PET, PLA is a 'greener' polymer, being produced from plants and food crops. After manufacture and subsequent processing of the polymer into the desired products, it can later be degraded into soil and humus, hence encouraging the re-cycling process. It does not suffer the bio-accumulation problems associated with the waste derived from conventional polyester, PET, which, of course, is derived from finite petroleum resources.

PROPERTIES OF PLA

The properties of PLA, as a textile fibre, in comparison with those of conventional polyester (PET) are shown in Table 1. PLA has better elastic recovery, better hydrophilicity, higher limiting oxygen index (LOI) and lower smoke generation than PET. Its lower refractive index allows PLA often allows it to be dyed to a deeper shade than PET, using a given concentration of disperse dye on fibres of similar dimensions. However, the melting temperature (T_m) of PLA, being much lower than that of PET (Figure 1), means the need to use much lower domestic ironing temperatures, particularly on woven constructions. Another disadvantage of PLA is its higher sensitivity to alkali, as compared with PET, resulting in some loss of fibre strength during subsequent wet processing (see later).

Table 1. Comparison of fibre properties between PLA and PET [5].

Fibre properties	PLA	PET
Specific Gravity	1.25	1.39
T_m (°C)	130-175	254-260
Tenacity (g/d)	6.0	6.0
Elastic recovery (5% strain)	93	65
Moisture Regain (%)	0.4-0.6	0.2-0.4
Flammability	Burn 2 min after flame removed	Burn 6 min after flame removed
Smoke Generation	63 m^2/Kg	394 m^2/Kg
Limiting Oxygen Index (%)	26	20-22
Refractive Index	1.35-1.45	1.54

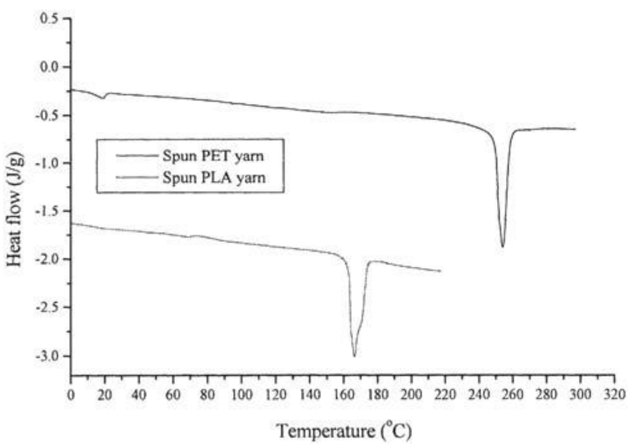

Figure 1. DSC scan of PET (top) and PLA (bottom) spun yarns.

Fibres of PLA have been successfully dyed with disperse dyes, although early practical experience suggested that the use of higher temperatures or longer times of dyeing could cause some degradation of the PLA. DyStar recommend dyeing conditions of 30 mins at 110°C and pH 4.5–5.0 (Figure 2.), the dyeing temperature being 20°C lower than that for PET fibres. At the same percentage depth of shade applied, a deeper shade is usually achieved on PLA fibres than on PET fibres of similar dimensions (dtex/filament), an exception being when (high wet fast) benzodifuranone dyes are used.

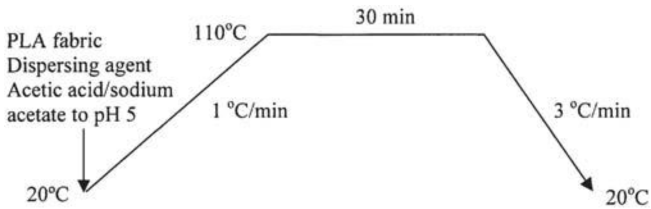

Figure 2. Disperse dyeing procedure used for PLA fibres.

The wet fastness properties of disperse dyes on PLA are slightly lower than those on PET, after a heat treatment (30 secs @130°C), designed either to convey dimensional stability to the fabric or to apply a chemical finish. A dyed Ingeo fibre fabric exhibited wash fastness properties, which were lower by 0.5–1.0 grey scale units than those of a PET fabric, dyed to the same visual depth of shade (and heat set for 30 secs @180°C). This is attributed to the higher degree of thermal migration of the disperse dyes to the surface of the Ingeo fibre, after heat treatment.

Over the last decade, large amounts of research have been directed into defining the optimum conditions for manufacturing and wet processing (dyeing) 100% PLA fibres. More recently, work has been directed towards the production and evaluation of blends of Ingeo and natural fibres. Blending of PLA with cotton would result in a host of desirable properties such as improved moisture regain, better next-to-skin comfort etc. However, before such a blend can be successfully commercialised, the preparation and wet processing requirements of the two fibres need to be compatible. For example, the preparation (eg. scouring, bleaching) and reactive dyeing processes required for the cotton component in the blend are generally conducted under warm alkaline conditions, the type of conditions which might reduce the strength of the PLA fibre component in the blend.

Consequently a study was carried out to examine the reduction in fibre/fabric strength (estimated by measurement of molecular weight (M_n) and ball burst strength values, respectively) as a result of typical wet processing conditions.

(a) Scouring but not bleaching (the cotton component) before high-temperature dyeing and 'reactive' dyeing.

–Drop in M_n during alkaline scouring (66,000→64,000)

–Drop in M_n during high-temperature dyeing (30 mins@110°C, pH 5) (64,000→57,800)

–Drop in M_n during dyeing (50°C) with ‘warm dyeing’ reactive dyes (57,800→53,600)
–Drop in M_n during dyeing (80°C) with ‘hot dyeing’ reactive dyes (57,800→54,400)

Since it is considered that a fabric blend would be sufficiently strong for commercial use if M_n 40,000 (ball burst strength 50 lb), the above results indicate that defined processing route does minimal damage to the strength of the blend.

(b) Scouring followed by cotton bleaching (plus high-temperature dyeing and ‘reactive’ dyeing)
- Drop in M_n during alkaline scouring (66,000→64,200)
- Drop in M_n during peroxide bleaching (64,200→63,100)
- Drop in M_n during high-temperature dyeing (30 mins@110°C, pH 5) (63,100→51,900)
- Drop in M_n during alkaline reduction clearing (51,900→51,000)
- Drop in M_n during dyeing (50°C) with ‘warm dyeing’ reactive dyes (51,000→50,000)
- Drop in M_n during dyeing (80°C) with ‘hot dyeing’ reactive dyes (51,000→49,500)

The results indicate that the bleaching process has a greater effect on reducing the strength of the fabric than simple scouring, a conclusion confirmed by ball-burst strength data on the fabric and SEM data. Nevertheless, provided that excessively long bleaching times were not used, both M_n and ball-burst strength values remains above the critical threshold for commercial acceptability.

CONCLUSIONS

PLA fibre possesses promising properties as a textile fibre when compared with the conventional polyester (PET) fibre. It can readily be dyed with disperse dyes at 110°C, generally producing shades of similar depth to those on PET fibres. However the fastness properties (both light and wet fastness after heat treatment) of PLA fibres are generally inferior to those of PET fibres. The use of PLA fibres in the textile industry is currently being expanded via the development of blends with natural fibres such as cotton and wool. Ingeo/cotton blends provide a desirable combination of the properties of both fibres. It has been shown that the blend can be processed under commercially realistic preparation and dyeing conditions, without a deleterious effect on the strength of PLA fibre in the blend.

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ECO INITIATIVES IN THE TEXTILE PIPELINE—A SOUTH AFRICAN EXPERIENCE

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INTRODUCTION

Although small by international standards, the South African clothing and textile sector has the potential to contribute significantly to South African export income and has been identified as one of eight key Industrial sectors with the greatest growth potential and marketability. Exports currently produce under 4 billion rand from a total production value in the region of 22 billion rand.[1] As it is a manufacturing sector under increasing pressure from external suppliers, particularly from China and India, strategies have been put into place by central government to work towards growing exports and slowing the growth of imports.

Increased environmental awareness and knowledge for the businesses in this sector together with improved environmental performance have been identified as important contributors to this strategy. Cleaner production initiatives have the duel advantages of improved economics in production and a better marketing profile and can therefore contribute to the growing of exports in the sector. In addition, the effects of invisible trade barriers relating to environmental management requirements can be minimized.

We will review the environmental initiatives and results of the Danish Cleaner Textile Production Project. Together with excellent examples of cost and resource savings, this project achieved additional positive outcomes including improved communications channels between the organizational role players and empowerment of employees working on environmental improvement projects.

In addition we will present an overview of some of the local technical research projects contributing to opportunities for environmental improvements in the sector. A range of locally grown fibres has been converted into innovative yarns and fabrics which meet industrial and geotechnical needs or have the potential to appeal to customers involved in fashion and design. We will also look at government initiatives to promote increased export opportunities and increased environmental responsibility by the manufacturers in this sector.

Finally, we will look briefly at the plans for future assistance to the South African clothing and textile sector in order to maintain the momentum in environmental improvements gained by the current activities.

CLEANER PRODUCTION IN COTTON GROWING

As the cause of major environmental impacts in the textile production pipeline, cotton growing was a focus area of the Danish Cleaner Textile Production Project running in

South Africa from 2000 to 2003. Using an entomologist and a cotton expert, the current polluting farming methods were reviewed. Existing cleaner cotton farming methods were available from the experience of small scale farmers who were unable to fund extensive inputs of pesticides, herbicides, fertilizers and defoliants as utilized by the commercial farmers.

Activities and achievements

The activities of the Cleaner Textile Production Project, Cotton Component covered feasibility studies, Integrated Pest Management Training (IPM) and the development of training aids with pegboard scouting techniques, which could be used easily even by illiterate small scale farmers. In addition farmer study groups were formed, a study tour for farmers to Denmark and Turkey organised, a highly experienced and respected cleaner production development adviser appointed, and the results of research and experience in the fields of IPM and organic cotton marketing were published.

Improvements were made through the IPM, scouting, demonstration projects, research and training and the dissemination of information. Activities included the study tour to Turkey and Denmark for 16 farmers and specialists, training for 185 people, research in 9 projects into cleaner production in cotton growing, and alternatives to the widely used GM cotton grown in South Africa. Four conferences and seven workshops were held to disseminate information within cotton farming. Publications included videos, posters, flyers, scout guides, magazines, newspapers, CD's and a website [2]

Check scouts were trained to assess insect populations and using research information on population sizes of pests which are known to cause crop damage, advice on the timing of chemical spraying was given. This Integrated Pest Management (IPM) was estimated, by participating farmers, to have resulted in yield increases of 15–20 % and savings of two crop sprayings, with estimated savings of R300/ha. Spray quantities were reduced because IPM enabled the crop to be sprayed when pests were at the larval stage, not adult. This attention to detail with the IPM techniques also resulted in improved farm management.[3]

The main constraints to further achievements were the resistance to change of both commercial and small-scale farmers and the insufficient financial incentives and research data to support further changes to organic or cleaner cotton growing techniques.

Cleaner Cotton Production Unit

In order to support ongoing initiatives in this area, the Cleaner Cotton Production Unit (CCPU) has been established, under the auspices of Cotton SA and managed closely with other cotton farming training initiatives. The objectives of the CCPU are to further support and strengthen awareness of Cleaner Cotton Production in the commercial and small-scale cotton growers in South Africa by

- Promoting Integrated Pest Management (IPM) amongst Cotton growers in order to strengthen and sustain the concept of Cleaner Cotton Production
- Strengthening awareness of cleaner production and specifically Best Management Practices & IPM, in order to expose the small-scale farmer to opportunities to enable him to consider organic or IPM as a viable option for future farming

The activities of the newly formed CCPU will include training programmes in all regions, dissemination & publication of information, demonstration projects in IPM on one commercial and four small-scale farms and check scout trials. To date their activities have included a newsletter distributed to the farmers, CDs distributed to farmers to inform about organic cotton production, a Cleaner Cotton Production Guide on laminated posters produced and distributed, articles on IPM in Farmers Monthly, three check scouts working on three demonstration projects each, commercial demonstration trials and an information day on cleaner production in cotton farming for both commercial and small scale farmers.

Continued support for these initiatives is required from Cotton SA in order to further promote the provision of information on cleaner production methods as an alternative to the intensive and polluting methods historically used by South African cotton farmers.

CLEANER PRODUCTION IN TEXTILE MANUFACTURE

The other major contributor to the environmental impacts from the textile production pipeline is the textile manufacturing sector with particular emphasis on the dyeing operation. This therefore was the other focus area of the Danish Cleaner Textile Production Project.

Activities and achievements

A wide range of technical activities were actioned including 4 study tours to Denmark, involving 40 key role players in the industry and related services. Also technical training for 106 people, 27 factory audits, 4 compressed air audits, 16 feasibility studies and 16 demonstration projects were completed. Dissemination activities included 4 conferences, 6 management awareness seminars, and 7 presentations, 16 workshops to industry groups on cleaner production activities, 5 training seminars and many publications including magazines, videos, CDs and a web-site.

A Cotton SA merit award has been competed for annually by textile manufacturers for the past three years. The award honours the company with the most environmental improvements and is hotly contested by the South African textile industry and used in marketing literature by successful companies. A past winner of this award won the inaugural national “Greening the Future Award” run by the Mail and Guardian newspapers and open to all South African Industry. This was considered an especial honour taking into account the historically polluting nature of the textile manufacturing industry.

Improvements in the environmental performance of Textile manufacturing in South Africa were made through questioning normal practices, thinking creatively, improving basic housekeeping issues, investing in technology, and catalytic in much of this change was the provision of waste minimisation training to the textile industry.

Cleaner Production results

Annual savings reported from Cleaner Production activities by participating companies as at June 2003 are detailed in Table 1.

Item	Annual financial saving	Annual unit savings
Water and effluent	4 970 000 (12)	790 000 kl (8)
Steam	2 560 000 (6)	31 000 tons (2)
Energy	565 000 (3)	
Heavy fuel oil	1 570 000 (3)	480 kl (2)
Chemicals	4 600 000 (6)	7 tons (1)
Waste	1 080 000 (4)	
Other*	3 660 000 (5)	
Total	19 005 000 (16)	

Table 1: Reported annual savings from textile manufacturers participating in the Cleaner Textile Production Project[4]

* Other includes aspects such as raw material and consumables

The figures in brackets are the number of companies reported in this table

In addition other positive outcomes were experienced by participating organizations including increased awareness at industry level, increased awareness at local government level, improved company to company interaction, improved company to regulator interaction, and increased awareness at tertiary education institutions. This was achieved through the training, study tours, workshops, and publications,

It is encouraging to note that a portion of these savings have been used by several companies towards the costs of improvements in their environmental management and in the reduction of environmental risks.

There is, however, still enormous scope for additional cost and resource savings within the South African textile manufacturing industry, both in terms of further savings from companies already embarked on cleaner production and waste minimization programmes and from companies who had not been involved in these projects to date. The realization of these opportunities needs to be the key objective of current projects in this sector, such as the UNIDO-funded National Cleaner Production Centre.

Clothing & Textile Environmental Linkage Centre

To support the momentum created by the Cleaner Textile Production Project, an extension was granted with the funding by the Department of Trade and Industry together with the Danish Government of the Clothing & Textile Environmental Linkage Centre from 2003 to 2005 and the Clothing & Textile Environmental Linkage Centre was created. The objectives of the Centre include

- Establishment and maintenance of a comprehensive repository of environmental information relating to the textile pipeline including the clothing and retail sectors.
  Raising awareness of environmental issues in decision makers throughout the textile and clothing pipeline.

- Increasing the knowledge of environmental issues and how to integrate these into product requirements
- Identifying and communicating market opportunities for textile products produced in an environmentally responsible manner.

Further details of the ongoing activities of the Clothing & Textile Environmental Linkage Centre are covered in later sections of this paper.

CLEANER PRODUCTION IN CLOTHING MANUFACTURE

In order to raise awareness of environmental improvements in the clothing manufacturing sector a Danish clothing consultant was utilized, to complete walk-through audits in four South African clothing manufacturers during March 2004. The major area of focus was the cutting department where the elimination of excessive fabric wastage can contribute economically and environmentally to a company's performance. Simple low cost improvements were recommended, suitable to the short run, labour intensive nature of the clothing manufacture in the medium sized manufacturers audited.

The observations and results of the audits were communicated to the companies involved with emphasis on potential cost savings from reduced wastage, and the inherent water, energy and other resource savings from reduced fabric usage. Typically, in many South African manufactured textiles, the resource savings when 100 kgs of fabric are saved can amount to between 6,000 and 10,000 litres water, with chemical and salt savings of 30kgs. In a water scarce country, with the inherent risks of salination of agricultural land, these savings can provide strong additional drivers for government support of cleaner production initiatives, from national, provincial and local water and agricultural authorities.

As expected, savings in fabric usage of over 2% were considered achievable with improved care and management of the basic processes within the cutting operation, together with some small investments. The implementation of many of these recommendations is currently in progress.

In order to build capacity, and facilitate skills transfer, South African skills training facilitators and cleaner production specialists participated in the audits, and will develop local training programmes in a similar manner to the highly successful waste minimisation training developed in the textile manufacturing sector.

The results of the completed audits serve as a demonstration to other South African clothing manufacturers of the opportunities for cost and resource savings and the specific recommendations and potential resultant savings are communicated throughout the industry via trade journals and workshops at tertiary education and technical training establishments.

ECOLABELLING & ORGANIC PRODUCTS

In order to demonstrate the ability of many South African textile and clothing manufacturers to meet ecolabelling criteria, a range of locally produced T-shirts were certified with the EU flower label for display at the World Summit in Johannesburg in September 2002. During 2003 several other manufacturers investigated certification with the EU flower and found that their operations and methods used would be capable of certification, should this be a requirement from a potential European customer.

Many manufacturers with current European export markets are already certified with the Oekotex label, with its criteria for their finished products. Certification with the wider life-cycle criteria of the EU flower is only allowed for specific products going into Europe and therefore has been limited in use to date.

The development of more production facilities with these certifications will remain demand driven at all times, both from the reasons of the rules for the label, and from the costs of certification where it is not a requirement by the customer.

Organic cotton production

Although South Africa has a large cotton growing industry, which at its peak volume could satisfy current local demand, there is no organic cotton grown in South Africa. Research was completed in 2003 into the production and marketing of organic cotton within the region, and it was concluded that as organic cotton lint is available from elsewhere in the sub-Saharan region, there is no immediate pressure to convert local production to organic.

Following a study tour to Turkey, one farmer in the Limpopo area has produced two crops of cotton from a small area of his farm, without the use of any chemicals on the crops. A pilot project has now been initiated to run trials in growing organic cotton in South Africa, and is currently at the planning stage.

The widespread promotion and use of genetically modified cotton by seed suppliers operating within South Africa remains an obstacle in the development of cotton production with improved environmental processes.

ENVIRONMENTAL MANAGEMENT SYSTEMS

One area encouraged by both South African National Government and European funders of development and environmental projects has been the certification of South African companies to international standards. There is widespread quality certification under ISO 9000/2000 within the textile industry, but environmental management system certification under ISO 14001 has been completed by only a handful of textile manufacturers. Those completing environmental certification are exporters who have found this to be a basic requirement when operating within the European markets.

Several textile companies are very close to achieving certification, but the barriers to completion are generally the costs of the auditing and certification procedure and the costs of administration of the systems. A further constraint is the shortage of skilled personnel resources at the required levels in these organizations to effect and maintain these management systems. Some of the physical improvements for risk reduction in environmental management can be costly and will generally be implemented over a prolonged period to comply with budget restrictions.

In general South African textile and clothing manufacturers are capable of achieving international standards and of obtaining certification, and this is achieved as soon as sufficient pressures are felt by the company from their potential International, and especially European customers.

NATURAL FIBRES

With its wide variations in climatic conditions there is enormous scope within the Southern African Region for the development of the production of a wide range of natural fibres for textile production.

The government supported, Centre for Scientific and Industrial Research (CSIR) has a specialist Centre for Fibres, Textiles and Clothing. In addition to technical support to the Industry, one of their key activities is the development of small scale and later commercial ventures in the growing, conversion and production of new textile products using natural fibres. Development projects in growing and producing textiles with hemp, sisal, flax and other plants have produced exciting and attractive fabrics, which are in varying stages of conversion to commercial ventures.

Key to this development has been a specially designed machine which "cottonises" the natural fibres by reducing the length and thickness of many of these fibres to a suitable length and tex for yarn and fabric manufacture. These shredded fibres can then be successfully blended with cotton to produce user friendly fabrics with a softer feel.

The large cactus like plant, S. Ethiopica has strong fibres in its leaves and these are being successfully converted to non-woven geotechnical fabrics. Work has started on the conversion of pineapple leaves into an attractive fashion fabric.

Wild silk project

Cocoons can be found on the camelthorn and mopane trees throughout a broad band of the region across Namibia, Botswana, Zimbabwe and the North West province of South Africa. A development project has therefore been initiated whereby the cocoons are harvested sustainably by the local population, when the moth larvae have left the cocoon. The cocoons are cleaned and degummed within the community and currently yarn is spun and fabric made in the CSIR research facilities in Port Elizabeth.

After completion of training, production will be moved this year to the North West province and production volumes will be increased to provide for commercial marketing and sale of these fabrics by the community. The wild silk fibres are blended with cotton to produce a beautiful, yet robust fabric with a potentially successful international niche market.

This project has many desirable aspects, with its community involvement, the utilization of a previously unused resource and long term sustainability as a result of the harvesting only of empty cocoons. The attractive, unusual fabric produced with its "Cinderella" fairy story should appeal to European and other export markets.

REMOVING TRADE BARRIERS

The South African government has been instrumental in negotiating preferential market access agreements with many key trading partners. The South African Free Trade Agreement with the European Union went into effect on 1st January 2000 and reached zero tariffs for many textile and apparel items by the end of 2003. The Africa Growth and Opportunity Act (AGOA) between South Africa and other sub-Saharan countries with the US took effect in March 2001 for apparel items and remains in force until September 2008.

The SADC trade protocols within the Southern African development community came into effect in September 2000 and provide for the phasing down of tariffs for 11 of the 14 SADC member countries. The participating member countries include a combined population of 135 million and aim to establish a free trade zone in this sub-Saharan region.

These preferential market access agreements can provide the platform for increased exports to developed markets, in the US and Europe and it is expected that these additional export opportunities will lead to further improved environmental management by South African companies from two major factors.

Firstly the pressures for responsible environmental management will be exerted by the increase in this environmentally concerned and aware customer base. Secondly the improved liquidity of the South African companies succeeding in this export market will enable them to budget expenditure on environmental improvements and construction for environmental risk reduction which had not been considered essential priorities when trading predominantly within the local market. So a combination of the need to improve will be combined with the accessibility of additional funds to improve environmental performance.

IMPROVING THE KNOWLEDGE AND AWARENESS OF RETAILERS, DESIGNERS AND BUYERS

One important means to provide ongoing pressure for improved environmental performance in the textile manufacturing industry is increased environmental demands from designers, buyers and retailers in the sector. The promotion of awareness and knowledge throughout the pipeline was therefore targeted as a key objective for the Clothing & Textile Environmental Linkage Centre. The ability of specifiers in the sector to be able to make informed choices can impact positively on the environmental performance of the clothing and textile manufacturers.

Students of Fashion and textile design have been targeted as necessary in providing for an informed future generation of designers in the industry. An Environmentally Friendly Design Competition was therefore launched this year, with workshops covering 485 students and 28 lecturers at 15 design departments in 8 tertiary institutions. 128 individual and group entries have been received to date and the 31 shortlisted entries will display their creations at the high profile Cape Town Fashion Week in August. Students from the winning groups will receive the prize of study tours to either the Danish Design School in Copenhagen or the Danish textile industry, Teko Centre in Herning. Already the levels of awareness concerning environmental considerations in lecturers and students of fashion and textile design have been substantially raised, and further promotion of the competition entries and winners by the media will continue this process further.

Fashion design is considered by the Department of Trade and Industry as one of South Africa's strengths and a key area for development, and it is important that our young designers understand the demands of their customers internationally regarding environmental considerations in their designs.

Retailers of clothing and yextile products can contribute enormously to the marketing and promotion of products with good environmental profiles. In South Africa, the leading retailer in this area is Woolworths, from the Marks and Spencer's stable. They have been leaders in the promotion of organic food in their food halls and have recently introduced a small trial range of organically produced cotton garments for children and ladies. Their influence over the local manufacturing industry in the clothing and textile sector is enormous and we have been lucky to have had the benefit of their input and committed support as members of the Steering committee for the Cleaner Textile Production Project and for subsequent initiatives. Other South African retailers, like the large Edcon group are starting to look at their environmental profile and investigating staff training and the reporting of environmental performance.

Another area to be targeted under the continuing Cleaner Textile Production inititative is the government buyers through tender requirements and tender adjudication procedures.

Currently the performance of potential suppliers is assessed on social and black empowerment criteria. There is an objective to include environmental criteria in these purchasing processes.

ENVIRONMENTAL LEGISLATION AND ENFORCEMENT

During the last ten years, there has been a revision of environmental legislation and many new, excellent, forward thinking laws have been passed. The environmental rights of all citizens have been entrenched by inclusion in our new constitution and the National Environmental Management Act together with separate water management and other legislation provides a very strong basis for good environmental governance at national, provincial and local levels. The inclusion, in legislation, of requirements for environmental impact assessments to be performed in advance of proposed developments, should ensure that any future developments are planned on a sustainable basis.

However enforcement levels have lagged behind this legal framework and hampered effectiveness of the legislation in several areas. This has been due, in part, to the initial lack of capacity to provide the enforcement and in part to the conflict in some areas between the provision of employment and the means of enforcement. Despite the willingness of government agencies to improve enforcement the priorites of government must remain on the provision of jobs and promotion of economic development to enable acceptable basic living conditions to be enjoyed by all South Africans, and improve the standard of living of the previously disadvantaged majority in the country.

Innovative solutions to these dilemmas are therefore required, and the advancement of cooperation between regulators and industry is important in these solutions. The Cleaner Textile Production project included both industry and regulators in study tours and cleaner production training with the objective of enabling win-win solutions to be found when regulators can work together with industry in assisting them to lessen their environmental impacts. Methods such as the "score system" where regulators and industry can together analyse the content and effects of industrial effluent on a long term basis instead of spot check sampling with its inherent conflict potential can contribute to achieving the required co-regulation.

A guide in cleaner production in the textile sector has been produced especially for regulators and this has been distributed free of charge to the relevant departments together with training in the use of the guide. Ongoing efforts, in particular from the regulators, are essential to continue this process and to reach a stage where our good legislation can become effective. This will need driving with external input to achieve these desired goals within a reasonable time scale.

SOUTH AFRICA AND THE NEIGHBOURING STATES

South Africa has been one of the founding partners of the new partnership for Africa's development, NEPAD, which provides a united platform for the advancement of African development. The goals of this initiative have gained support from many key northern partners including the UK's Development Ministry, so that Africa has been placed at the forefront of the UK development agenda.

NEPAD provides a vision and strategic framework for Africa's renewal and among its priorities is good economic governance, regional co-operation and capacity building. Two of its priority sectors for policy reforms and increased investment are the environment and market access. Several identified objectives in the manufacturing sector relate to the promotion of international standards and certification within the region as a support to the growth of trade with the developed world.

Improved communication and closer ties between the sub-Saharan countries in the last ten years have gone a long way to removing the barriers of distrust of South Africa caused both by the previous political base and the ongoing situation of the size and economic muscle of South Africa relative to many of its neighbouring states.

Many of the negotiated preferential trade agreements have included neighbouring states and this achieves greater unification of the region and stronger shared goals for development and responsible governance. South Africa has been able to offer considerable technological assistance to neighbouring states and this assists with strengthening the economic base in the region in order to provide a stronger platform for improvements to environmental responsibility.

There are several regional initiatives in the textile and clothing sector, including the Sustainable Trade and Innovation Centre, Southern African Regional Consultation Workshop which was hosted in South Africa in December 2003 with support of Department of Science and Technology. This organization promotes trade and market access in sustainable goods and services between developed and developing countries and is supported in the sub-Saharan region by South Africa.

ONGOING INFORMATION AND SUPPORT FOR ENVIRONMENTAL IMPROVEMENTS IN THE SOUTH AFRICAN CLOTHING & TEXTILE PIPELINE

The current life spans of both the clothing and textile Environmental Linkage Centre and the National Cleaner Production Centre continue until the end of 2005. The Department of Trade and Industry, both in the Trade and Investment, Clothing & Textile Section and in the Environmental Section are committed to continuing to provide support for this key Industrial sector in aspects of environmental improvements. Firm agreement on what form this support should take, and under which umbrella it should be located, has yet to be confirmed, but is expected to be finalized early in 2005.

Further support for the ongoing provision of environmental support to the clothing and textile sector will come from all other interested and affected parties from within the three spheres of government, industry, retailers, specialists and organized labour. The steering committee which has guided the Cleaner Textile Production Project, the Clothing & Textile Environmental Linkage Centre and the National Cleaner Production Centre contains representatives from these spheres and this has improved the knowledge, understanding and commitment of these key players to environmental improvements in this sector.

CONCLUSIONS

The ability of many South African Textile manufacturers to meet European and US standards is evident. The main barrier to continued environmental improvements is the lack of pressures on manufacturers to embark on further expenditure on these improvements.

The responsibility for providing this ongoing pressure will rest mainly with government agencies, who together with increased consumer knowledge and demand can continue to fuel the process. Opportunities for exports, particularly to the European markets would create further demand pressures on industry, for environmental improvements including more formal certification. In addition, where savings can be achieved from waste minimization and other cleaner production efforts, this will offset, to an extent, and provide additional motivation, for further in-house improvements with net costs rather than net savings. The need for ongoing assistance and support from a central, efficient and economically effective resource base will continue if these environmental improvement objectives are to continue to be realized.

South Africa is currently a country experiencing a wealth of positive changes throughout government, business and civil society, and it is the belief of the authors that this increased flexibility and open-mindedness, together with national government commitment for improvement, will continue the process of reducing the environmental footprint of our clothing and textile industry.

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