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BIOTECHNOLOGY IN TEXTILES

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INTRODUCTION

My initial interest in and awareness of the potential of biotechnology to the fibre, textile and clothing industries began several years ago when I used to work at the Shirley Institute (as it was then), now the British Textile Technology Group.

At that time, an enthusiastic group of researchers under Dr Brian Sagar was doing much to pioneer the application of biotechnology to a variety of textile problems. This interest is still being actively pursued at the BTTG and I will touch upon several aspects of their work in the course of this talk.

More recently, my company, David Rigby Associates, which specialises in technology, business and marketing strategy issues within the international textile supply chain, was commissioned towards the end of 1994 to prepare a state-of-the art report on behalf of the Department of Trade and Industry (DTI), to review the development and commercial potential of biotechnology in the UK textile industry.

This commission was part of a wider project aimed at supporting the DTI's Biotechnology Means Business campaign. Similar reports have been prepared for the Waste Treatment, Food, Speciality Chemicals and Pulp and Paper industries. These were all chosen as sectors where there is a high proportion of Small and Medium-sized Enterprises (SMEs) as well as a broad range of medium-value products. Unlike high technology, high product value industries such as pharmaceuticals where many of the early commercial applications of biotechnology emerged, it was reckoned that the science base in these sectors might need more information, support and encouragement.

The DTI report on textile applications of biotechnology has just been published. I therefore first want to review the scope of that report and the diversity of ways in which biotechnology is already, and will increasingly, impact upon the textile industry as a whole. I will then focus upon some more specific implications for the finishing industry.

WHAT IS BIOTECHNOLOGY?

While I was interviewing various companies and organisations in the course of researching the report, I was advised:

> "You can tell finishers that you have a wonderful new chemical formulation but don't mention the word biotechnology - they won't understand or want to know".

In contrast to this, biotechnology's enthusiasts hail it as the third industrial revolution, comparable to steam power and the microprocessor in the way that all of these have transformed the world we live in, not just making existing tasks quicker and easier but creating fundamental new products and possibilities, as well as consumer expectations.

It is easy to succumb to the hype surrounding any promising area of innovation. Part of the key to reconciling these two points of view is to understand just how far the new technology has already impacted upon how we live and work (even in ways that we may already take for granted) and what are the realistic time scales for its further development and application.

'FARMING WITH BUGS'

Simple cellular organisms such as yeast have been used for millennia, knowingly or otherwise, to make bread, beer and wine. Other microbes and natural extracts have been used for just as long in cheese making, food preparation and as the basis of much early medicine. Most of this has been accomplished with little or no understanding of the basic science involved. However, the susceptibility of all of these processes to something going wrong is also widely recognised. Bread does not always rise perfectly; beer and wine can go sour.

Most industrial applications of biotechnology are still based upon fermentation processes using bacteria and enzymes to digest, transform and synthesise natural materials from one form into another. It is not surprising perhaps that biotechnology is often described as "farming with bugs". It is also easy to conclude that the whole field of biotechnology is still something of a 'black art'.

For example, the active agent in many bio-transformation processes is an enzyme rather than the cellular living organism itself. Enzymes are not alive themselves but are complex chemical catalysts which can, in principle, be produced by a number of different methods, including non-biological synthetic routes. (That said, biological systems still offer the most flexible and economic means of production in most cases even though they can suffer from the inherent variability of all natural processes).

Each of the well known types of enzymes encountered in textile applications (cellulases, amylases, proteases, lipases etc.) are really extended families of related compounds. Any commercial preparation of, say, cellulase (an enzyme which breaks down cellulosic materials such as cotton and viscose) will be a complex mixture of endocellulases, exocellulases, cellobiohydrases, cellobiases and several others. Each of these will have a specific action on different parts of, say, a cotton fibre. Their susceptibility to heat, pH, chemical degradation etc. will all vary, as will their relative proportions in any mixture made from different micro-organisms or from a single micro-organism under slightly varying conditions.

THE SYSTEMATIC APPLICATION OF BIOLOGICAL SCIENCE

The contribution of science has been to understand to a much greater extent what exactly are the active components and mechanisms of the "bugs" and their derivatives and therefore to begin to control, manipulate and reproduce their capabilities in a more systematic and intelligent fashion.

Modern biotechnology has also brought forward a number of techniques which do not rely on microbes and enzymes at all but which directly modify and harness the power of the DNA molecule, the engine house of any biological system.

In particular, a number of key technologies have begun to come together to provide the engineering tools needed for consistent and economic industrial-scale production. First and foremost among these is genetic engineering.

GENETIC ENGINEERING

With an improved understanding of how different genes are responsible for the various characteristics and properties of a living organism, techniques have been developed for isolating these active components (in particular, the DNA which carries the genetic code) and manipulating them outside of the cell.

The next step has been to introduce fragments of DNA obtained from one organism into another, thereby transferring some of the properties and capabilities of the first to the second. For example, scientists working for the leading enzyme producer, Novo Nordisk of Denmark, discovered that an enzyme produced in minute quantities by one particular fungus had very desirable properties for dissolving fats. The relevant genes were 'spliced' into another micro-organism which was capable of producing the desired enzyme at much higher yield. The process is now being applied on an industrial scale by Novo to produce Lipolase, an enzyme used in washing powders and liquids. The commercial process to make what is widely regarded as the first industrial enzyme to be produced by genetic engineering was perfected in as little as two years, driven by the urgent need to help a leading Japanese detergent manufacturer, Lion, fight off competition from a rival.

MONOCLONAL ANTIBODIES

Monoclonal antibodies are protein molecules with an amazing ability to 'recognise' specific substances, even at extremely low concentrations. They were first developed for use in medicine to detect and to target cancer cells - the so-called magic bullet approach; they have also been used for pregnancy testing.

More recently, a York-based company, Biocode, has developed monoclonal antibodies as a very sensitive marking tool for the prevention of counterfeiting. The markers themselves are cheap and safe substances which can be applied to foodstuffs, drinks and textiles in concentrations of a few parts per million or less.

The 'codes' embodied in these markers are completely secure but can readily be detected by customs or trading standards inspectors using simple equipment in the field. Carefully selected monoclonal antibodies will bind themselves to the marker molecules and produce a readily visible colour change. The technology has already been evaluated for the marking of branded denims. Methods have been perfected for use in nylon and acrylic resins and markers can also be incorporated into dyestuffs or applied to surfaces using ink-jet printers.

DNA PROBES

DNA probes are another technology which has grown out of genetic engineering research. Short pieces of DNA can be designed to stick very specifically to other pieces of DNA and thereby, to help identify target species. The technique can be applied, for example, to distinguish cashmere from wool and other goat hairs.

The initial impetus for application of DNA probes in the textile industry has come from importers and processors of speciality animal hairs who have seen a surge in trading and labelling fraud, especially in the wake of recent high fibre prices. Now, similar probes are being identified to distinguish between cotton, ramie, kapok, coir, flax, jute and hemp.

Originally, there were very great problems in extracting DNA from fibres without excessive degradation. BTTG achieved a breakthrough in 1988 when they demonstrated how to do this and have since developed a series of DNA probes which form the basis of a recently launched commercial service. Eventually, it should be possible for the technique to be developed for field use instead of just in the analytical laboratory.

BIOSENSORS

A third way in which biological systems can be used as extremely sensitive analytical and control tools is in biosensors. These employ some change produced by very small quantities of biologically active agents to measure and therefore, in principle, to control chemical and physical reactions.

For example, BTTG has been working on the use of certain fungi which are capable of absorbing and concentrating heavy metal ions such as lead, copper and cadmium. Resultant changes in the conductivity and dielectric properties of the fungi can be used to measure these species in a process or effluent stream relatively cheaply and easily. (This property of fungi also has scope on a larger scale for the purification of effluents containing such substances).

Biosensors are also likely to make an early impact in areas such as BOD measurement and process control, including perhaps monitoring of some of the new generation of enzyme processing technologies which will be discussed below.

In the longer term, applications can be envisaged which incorporate biosensitive materials into textiles, for example to produce 'intelligent' filter media or protective clothing which detects as well as protects against chemicals, gases and biological agents.

APPLICATIONS TO FINISHING

These analytical and control applications are an interesting illustration of how 'non-traditional' aspects of biotechnology are fast contributing towards its wider commercial application and development. However, the main economic impact on the textile industry in general and upon finishers in particular is likely to emerge in three distinct areas: new processes, improved environmental protection and new or modified raw materials. These are discussed below.

PROCESSING WITH ENZYMES

The use of enzymes in textile processing and after-care is already the best established example of the application of biotechnology to textiles and is likely to continue to provide some of the most immediate and possibly dramatic illustrations of its potential in the near- to medium-term future.

For example, the use of amylase enzymes for the desizing of woven cotton and man-made fabrics has been known for most of this century and is widely practised today. The use of proteases, cellulases and lipases as additives to textile after-care detergents has also developed considerably since the 1960s.

Now there is virtually no area of fibre and textile wet processing for which enzyme technology does not hold out some promise of radical improvement and change to present day practices. This is not to say that such advances are always imminent. Many important technical and cost issues still need to be resolved. There are also some less obvious organisational and competitive barriers to diffusion and take-up of the new technology to be overcome. The following observations highlight current technical progress in each major area of wet processing but also point out some of these other considerations.

FIBRE PREPARATION

The retting of flax has always been one of the major costs and practical limitations to the more widespread use of what is, potentially, a major indigenous source of cellulosic fibre in Northern Europe. The traditional routes are 'dew' and 'water' retting which respectively involve high handling costs (turning the fibre in the fields) or environmental costs (biological loading of water courses). They are also too susceptible to the vagaries of the Northern climate.

Various attempts have been made since the late 1970s to introduce more rapid and controllable enzyme retting processes but these have proved difficult to scale up to a commercial level. Now the Agricultural Research Institute of Northern Ireland (ARINI) has shown that pre-treatment of the flax with sulphur dioxide gas brings about sufficient breakdown of the woody straw material to speed up enzyme retting whilst preventing excessive bacterial or fungal deterioration of the fibre.

The UK "Fibrelin" project, involving several industrial and academic partners and of which this work is only a part, has also been looking at improved mechanical processing methods and new products for use of UK grown flax. This work could lead to a major revival of flax and linen production, with obvious implications for the finishing sector.

The carbonisation process in which vegetable matter in wool is degraded by treatment with strong acid and then subjected to mechanical crushing can, in principle, be replaced by selective enzyme degradation of the impurities. Claims have been made by Polish researchers for such a "Biocarbo" process but work still needs to be done to achieve acceptable throughput rates.

FABRIC PREPARATION

Desizing using amylase enzymes has been well established for many years. However, there is still considerable scope for improving the speed, economics and consistency of the process, including the development of more temperature stable enzymes as well as a better understanding of how to characterise their activity and performance with respect to different fabrics, sizes and processing conditions e.g. for pad-batch as opposed to jigger desizing.

There is also work to be done on optimisation of BOD levels ensuing from enzyme desizing. The very success of these methods in breaking starch-based sizes down into more easily biodegradable short chain carbohydrates can actually appear to increase contamination measures based upon short term indices such as residual consumption of oxygen after 5 days - BOD(5).

Scouring and bleaching would be attractive targets for enzyme-based processes but are not yet commercial prospects. Researchers at several centres, including BTTG, have shown that pectins, waxes and colour can all be removed but that residual seed coatings remain a problem. A new generation of enzymes, the xylanases which are currently used in the wood industry, may offer an eventual solution.

Another desirable development would be enzymes capable of destroying honeydew sugars, insect secretions which cause stickiness and severe processing problems for cotton spinners.

An already established application, however, is the use of catalase enzymes to break down residual hydrogen peroxide after, for example, a pre-bleach of cotton that is to be dyed a pale or medium shade. Reactive dyes are especially sensitive to peroxides and currently require extended rinsing and/or use of chemical scavengers. Several commercial enzyme products are already on the market for this purpose.

FINISHING

Biostoning and the closely related process of biopolishing are perhaps attracting most current attention in the area of enzyme processing. They are also an excellent illustration of how different industry structure and market considerations can affect the uptake of enzyme technology.

Conventional stone washing uses abrasive pumice stones in a tumbling machine to abrade and remove particles of indigo dyestuff from the surfaces of denim yarns and fabric. Cellulase enzymes can also cut through cotton fibres and achieve much the same effect without the damaging abrasion of the stones on both garment and machine; moreover, there is no need for the time-consuming and expensive removal of stone particles from the garments after processing. Machine capacity can be improved by 30-50% due to reduced processing times, product variability is reduced and there is also less sludge deposited in the effluent.

Disadvantages can include degradation of the fabric and loss of strength as well as 'backstaining' (discoloration of the white weft yarn, resulting in loss of contrast). A slight reddening of the original indigo shade can also occur. However, careful selection of neutral or alkaline cellulases able to function in the pH range 6-8, albeit at higher cost and reduced activity compared with acid cellulases (pH 4.5-5.5) can control these problems. Now, processors are learning to play more sophisticated tunes such as achieving a peach skin finish by use of a combination of stones and neutral cellulase.

Biostoning was first introduced to the European industry in 1989 and spread to the USA in 1990; its application is now global. Uptake by specialist denim garment processors is almost 100% and provides an excellent example of how rapidly and completely a biotechnology-based process can transform an industry. However, the economic advantages of the process are unusually clear cut and directly benefit the immediate user, the stonewasher. Initially, consumers noticed little or no difference to the products they bought; there was therefore no need to promote and sell the new idea to a wider market. This is only just beginning now as the scope of the technology for producing more sophisticated finishes emerges.

Biopolishing employs basically the same cellulase action to remove fine surface fuzz and fibrils from cotton and viscose fabrics. The polishing action thus achieved helps to eliminate pilling and provides better print definition, colour brightness, surface texture, drapeability and softness without any loss of absorbency.

The technique is particularly promising for us with the new generation of solvent spun cellulosic fibres such as Courtauld's Tencel and Lenzing's Lyocell. Biopolishing can be used to clean up the fabric surface after the primary fibrillation of a peach skin treatment and prior to a secondary fibrillation process which imparts interesting fabric aesthetics.

A weight loss in the base fabric of some 3-5% is typical but reduction in fabric strength can be controlled to within 2-7% by terminating the treatment after about 30-40 minutes using a high temperature or low pH 'enzyme stop'. Both batch and continuous processes can be employed as long as there is some degree of mechanical action to detach the weakened fibres. One area that still poses problems is that of tubular cotton finishing. Here the fibre residues tend to be trapped inside the fabric rather than washed away.

The technology was first developed in Japan as far back as 1988 and used for softening and smoothing of cotton fabrics without the application of other chemicals; it was also used to upgrade ramie as a cotton and linen substitute, and to upgrade lower qualities of cotton. However, its introduction into Europe did not take place until 1993 and its adoption since then much has been slower than biostoning. A few German and Italian finishers still lead the way here while take up in the UK has so far been confined to a very few trial applications.

The reasons for this are not entirely technical or economic. They are also connected with the fact that there are fewer intrinsic benefits to the finisher who adopts the technology until the end-user market is educated to value and to pay for the improved performance and aesthetics. As with other innovations in the past, it is not clear even then that the finisher would retain all of the value created; converters, garment manufacturers and retailers would want their share of the cake.

In recognition of the need to develop end-user demand, major enzyme suppliers have resorted to consumer marketing to a far greater extent than they ever needed for the introduction of biostoning. For example, Novo Nordisk is promoting a registered BioPolishing label logo but this is likely to be a long term process.

WOOL PROCESSING APPLICATIONS

The International Wool Secretariat (IWS) has, together with Novo, been developing the use of protease enzymes for a range of wool finishing treatments aimed at increased comfort (reduced prickle, greater softness) as well as improved surface appearance and pilling performance. A new range of products, Biosoft PW, has just been launched onto the market.

The basic mechanisms closely parallel those of biopolishing. However, the treatment is so far only effective on wool which has been previously chlorinated in loose, top or garment form in order to remove or weaken the surface scales of the fibre. It has also initially been aimed at knitwear rather than woven fabrics.

Longer term hopes are that improved enzyme treatments will allow more selective removal of parts of the wool cuticle, thereby modifying the lustre, handle and felting characteristics without degradation or weakening of the wool fibre as a whole and without the need for environmentally damaging pre-chlorination treatment.

OTHER PROTEASE APPLICATIONS

Protease enzymes similar to those being developed for wool processing are already being used for the degumming of silk and for producing sandwashed effects on silk garments. Treatment of silk-cellulosic blends is claimed to produce some unique effects.

Proteases are also being used to wash down printing screens after use in order to remove the proteinaceous gums which are used for thickening of printing pastes.

TEXTILE AFTER-CARE

Enzymes have been widely used in domestic laundering detergents since the 1960s. Some of the major classes of enzyme and their effectiveness against common stains are summarised below.

Enzyme	Effective for
Proteases	Grass, blood, egg, sweat stains
Lipases	Lipstick, butter, salad oil, sauces
Amylases	Spaghetti, custard, chocolate
Cellulases	Colour brightening, softening, soil removal

Early problems of allergic reactions to some of these enzymes have now largely been overcome by the use of advanced granulation technologies such as Novo's T-granulate and Genencor's Enzoguard. Modern enzyme systems have reduced the use of sodium perborate in detergents by 25% along with the release of harmful salts into the environment. Energy savings of at least 30% have also been achieved by being able to wash clothes at lower temperatures.

However, enzymes still have to make a corresponding impact upon the commercial laundering market. One of the problems here has been the level of investment in 'continuous-batch' or tunnel washers. These typically afford a residence time of 6-12 minutes which is not long enough for present enzyme systems to perform adequately. More efficient methods of 'enzyme kill' are also required because of the extent of water recycling in modern washers.

Future developments in the field of textile after-care may include treatments to reverse wool shrinkage as well as alternatives to dry cleaning.

CARING FOR THE ENVIRONMENT

Natural and enhanced microbial processes have been used for many years to treat waste materials and effluent streams from the textile industry. Conventional activated sludge and other systems are generally well able to meet BOD and related discharge limits on most cases. Occasionally, space limitations in older companies or other local factors can combine to require the development of more compact and effective biologcal and/or chemical flocculation systems but the technology is basically well understood.

However, the industry does face some specific problems which are both pressing and intractable. They include colour removal from dyestuff effluent and the handling of toxic wastes including PCPs, insecticides and heavy metals. Not only are these difficult to remove by conventional biological or chemical treatment but they are also prone to 'poison' the very systems used to treat them. The microbes employed need to be versatile and robust towards complex and often varying environments.

COLOUR REMOVAL

Reactive dyes are particularly difficult to treat by conventional methods because they are not readily adsorbed onto the activated sludge biomass where they could be degraded. Zeneca Environet is currently pioneering one approach to this problem which involves direct microbial attack on the azo-linkage of organic dyestuffs, leading to their complete degradation in solution. Pilot units are already running in a couple of major UK dyehouses.

Alternative approaches being evaluated in the UK include the use of biologically active materials such as chitin to absorb colour. Researchers in some developing countries are experimenting with more readily available and cheaper local sources of biomass such as straw pulp and even residues from biogas reactors.

METAL AND TOXIN REMOVAL

The potential for using selected fungi to absorb heavy metals from effluent streams has already been touched upon. Species such as the ligninase-producing white wood rot fungus have already been successfully applied in the paper and pulp industries for removing lignin-bound chlorine. They are also effective against biphenyls, aromatic hydrocarbons and chlorinated compounds such as PCPs and DDT. Other fungi have been used to remove highly toxic tannins from tannery effluents.

TEXTILE SUPPORTS

A novel approach to promoting aerobic degradation in contaminated lagoons and preventing the development of malodorous and unpleasant anaerobic processes has been pioneered in Germany. Here a development based on a 3-D 'biomat' of knitted polyester monofilament has been patented by Hoechst as a support for the micro-organisms. The mat is stable and resistant to compression; its open supporting structure counteracts the build-up of anaerobic sludges on the bottom of the lagoon.

NEW AND MODIFIED RAW MATERIALS

The final area that I want touch upon is the relevance to finishers of biotechnology developments in the area of new and modified raw materials. In particular, the application of genetic engineering to modify the growth characteristics and properties of virtually all the major natural fibres is proceeding at a considerable pace. Completely new fibres and other materials capable of being used in textile processes are emerging although development timescales here are expected to be somewhat longer.

Cotton Genetic engineering research upon the cotton plant is being aimed towards two main goals:

- improved insect, disease and herbicide resistance (short term)
- modification of fibre properties and performance (longer term).

The use of synthetic pesticides is becoming a major issue in the USA and elsewhere that cotton is grown; it is also an increasingly serious challenge to the 'green' image of cotton in consumer markets. Biopesticides based on a strain of soil bacteria known as Bt are already being used for control of caterpillar and beetle pests in a wide variety of fruits, vegetables and crops. More stable, longer lasting and more active Bts are now being developed for the suppression of loopers, bollworms, budworms and armyworms in cotton.

The next stage will be to introduce greater insect and herbicide resistance by direct genetic engineering of the cotton plant itself. One of the largest cottonseed suppliers in the USA, Calgene, expects to have a commercial variety available this year providing greater tolerance to the major herbicides used for weed control. Insect resistance is also being developed using a 'wound-inducible promoter' gene capable of delivering a large but highly localised dose of toxin within 30-40 seconds of an insect biting.

The immediate implications of these developments for finishers will obviously be to reduce greatly the levels of chemical contaminant washed off cotton yarns and fabrics during scouring and bleaching. The longer term implications of genetic research on cotton could be far more fundamental. Identification and manipulation of the genes responsible for fibre formation will allow modification of appearance, length, micronaire and strength. Other changes directly relevant to finishers could include absorbency, chemical reactivity with dyestuffs etc., shrinkage and crease resistance.

Practical results achieved so far include development of a cotton fibre with 50% greater strength than its 'parent'. Coloured cottons are also being developed, not only by conventional genetic selection but also by direct DNA engineering to produce, for example, deep blue cotton for denim production. The prospect is even being held out of encouraging natural polyesters such as polyhydroxybutyrate (PHB) to grow within the central hollow channel of the cotton fibre, thereby creating a 'natural' polyester-cotton.

A US biotechnology company, Agracetus, has already been awarded, somewhat controversially, a patent covering the entire cotton 'genome' (genetic structure) and is setting up a company called FibreOne to create, produce, market and license these speciality products.

SHEEP, GOATS

A host of developments in sheep and goat genetics are being carried out with the aim of producing more efficient feeding methods, greater insect and pest resistance, softer and finer fibres and even a technique for biological wool harvesting. Injection of a special protein temporarily interrupts the growth of hair and after four to six weeks, a natural break appears at the base of the fibre. The fleece can then be peeled off the sheep, allowing an increase in daily shearing output from 120 to 300 fleeces per team. The technology is already proven; however some concern still exists over levels of abortions in ewes and further research is needed.

In the UK and Northern Europe, much effort is being focused upon producing finer wools from varieties of sheep that can survive and prosper in less hospitable climates as well as boosting the adaptability of exotic species such as cashmere, mohair and vicuna.

FLAX, JUTE, ETC

Enhanced methods of processing flax fibres using enzymes have already been mentioned. In the UK, the Scottish Agricultural College has also been working on various aspects of flax genetic improvement using biotechnological means. Advances here could substantially improve the attractiveness of flax growing in Scotland and Ireland again and lead to a resurgence in the importance of indigenously produced linen textiles.

SILKWORMS

Last but not least, research is being conducted in China and elsewhere to overcome the dependence of silkworms upon mulberry leaves, improve the strength and fineness of silk, increase viral resistance, and even produce coloured fibres.

NEW FIBRE SOURCES

Several possibilities exist for producing entirely new fibre materials, so-called biopolymers, using biotechnological process routes. Zeneca has already produced a naturally occurring polyester, PHB, by bacterial fermentation of a sugar feedstock and commercialised it as Biopol. The polymer is stable under normal conditions but biodegrades completely in any microbially-active environment. Biopol is still regarded as being too expensive (at £5-10/kg) for many textile applications but has been evaluated for use in medical sutures as well as environmentally friendly fishing nets. Attempts are currently being made to clone the active genes that produce the polymer into a higher yielding natural crop such as oil seed rape.

Other biopolymers with textile potential include polylactates (being developed in Japan) and polycaprolactones, already being investigated in the USA for medical applications.

BACTERIAL CELLULOSE

Japanese companies have already produced speciality papers and nonwovens based on bacterially grown cellulose fibres; these are extremely fine and resilient and are being used for e.g. manufacturing diaphragms for stereo headphones. Future applications may include specialised filters, odour absorbers and reinforcing blends with aramids. In the UK, BTTG has been looking at the wound healing properties of bacterial cellulose for several years.

FUNGAL HYPHASE

The metal and toxin absorbing properties of fungi have already been discussed. A further stage in this development is to utilise the long filament structures of certain fungi as textile fibres. Considerable limitations are likely to remain to the spinning or other textile processing of such fibres but applications are already being found as reinforcements for wet-laid nonwovens where they act as efficient binding agents in concentrations as low as 5% whilst improving filtration efficiencies considerably.

GENETICALLY MODIFIED MICRO-ORGANISMS

Attempts have been made to transfer certain advantageous textile properties into other micro-organisms where they can be more readily reproduced by bulk fermentation processes. For example, research has been undertaken, initially in the UK and later by the US Army, to transfer spider DNA into bacteria with the aim of manufacturing proteins with the strength and resilience of spider silk for use in bullet proof vests.

DYESTUFFS AND INTERMEDIATES

A final example which is worth mentioning as being particularly relevant to finishers concerns various attempts that have been made to synthesise bacterial forms of indigo as well as fungal pigments for use in the textile industry. BTTG has once again been active in this sphere and has shown that certain microfungi are capable of yielding up to 30% of their biomass as pigment. Potential non-textile applications include food industry colorants. However, leading dyestuff manufacturers are still sceptical about the long term viability of such routes and have been slow to support such research.

CONCLUSION

This note of caution needs to be echoed across the whole spectrum of biotechnology developments. Although biological systems offer many attractive possibilities and new approaches to all sorts of problems and needs, considerable advances are still being made in 'conventional' technologies such as catalysis, chemical synthesis and physical fibre modification which need to be kept in perspective. There is also still great concern in society about the unbridled advance of biotechnology, especially with regard to the modification of natural species with possible unknown long term consequences.

With that caveat, the table below suggests possible time scales for the significant commercial implementation of some of the technologies discussed here. In compiling these, I was conscious of the very considerable amount of progress still to be made in many areas but also of how rapidly a new biotechnology (such as biostoning) can be developed and applied where a clear economic justification and market need exists.

ESTIMATED COMMERCIAL DEVELOPMENT TIMESCALES

Application	Technology/Usage	Timscale
Process Aids	Fibre retting and carbonisation enzymes	2-5 years
	Desizing enzymes	established
	Scouring and bleaching enzymes	10+ years
	Finishing enzymes - biostoning, biopolishing etc	0-2 years
After Care	Proteases, cellulases, lipases	established
Modified Producing Organisms	Cotton	2-5 years
	Sheep, goats, etc	2-5 years
	Flax, jute, etc	2-5 years
	Silkworms	5+ years
New Fibre Sources	Biopolymers (PHB, polylactates etc)	2-5 years
	Bacterial cellulose	5+ years
	Fungal hyphae	10+ years
	Genetically modified micro-organisms	10+ years
Dyestuffs and Intermediates	Bacterial indigo and related products	10+ years
	Fungal pigments	10+ years
Fibre Identification and Analysis	DNA probes for species identification	0-2 years
	Security marking	0-2 years
Caring for the Environment	Colour removal	0-2 years
	BOD and sludge reduction	established
	Metal removal	2-5 years
New Uses for Textiles in Biotechnology	Supports for immobilised cells and enzymes	5+ years
	Biosensors	2-5 years