Future Woolscapes

Research Brief

Project Dolly:

Impacts of the New Technologies to 2029

Position Paper

16 June 2004

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Introduction

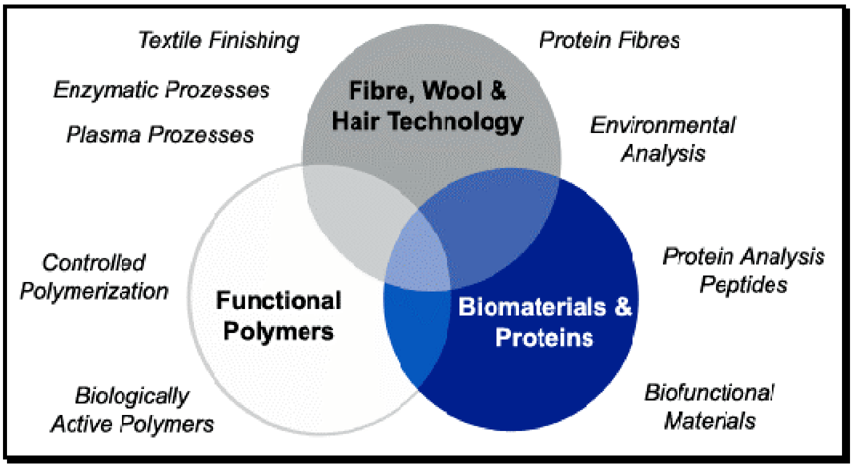
This paper is written to support the *Future Woolscapes* project which is examining the question: *"What might the wool industry look like in 2029 – and what are the implications of that?"*

The aim of this paper is to examine the likely impacts of the new technologies on the industry over the next quarter century.

The paper identifies and defines the new technologies. It reviews their current and possible future applications in the world at large, and then specifically within the wool industry. It examines the threats and opportunities posed by the new technologies, and concludes with recommendations for the wool industry and for the *Future Woolscapes* project.

The New Technologies Defined

New technologies is a broad term for the application of recent major scientific developments that are perceived as having the greatest potential to change the human condition in the coming decades. This section defines those areas which are likely to impact the wool industry in the time horizon of the project: *Materials Science*, *Nanotechnology*, *Biotechnology, Genetics*, and "*Organic Machines*".



The meeting of many sciences – graphic by **German Wool Research Institute, Aachen University**[1]

Materials Science is the study of the characteristics and uses of all types of natural and synthetic inorganic materials, from metals, ceramics and crystals to plastics and semi-conductors. [2]

New materials – such as superconductor ceramics enter the domain of Materials Science when developed in their respective highly specialised fields. Closely related to Material Science are the disciplines **Surface Science** and **Surface Chemistry** which are concerned with studying and altering the surface characteristics of materials, such as stain resistance.

Nanotechnology is technology of studying and fabricating at atomic or molecular level. The nano (*n*) metric prefix means one billionth of a unit or 10^{-9}. A nanometre is "three or four atoms wide" and, strictly, Nanotechnology is the discipline that deals with things smaller than 100 nanometre or one-tenth of a micron.

The media often confuse nanotechnology with **MEMS**, *Micro-Electro-Mechanical Systems*, the study and fabrication of micro machinery and objects[3]. Medical MEMS applications - such as tiny machines to clear clogged arteries - have become the public face of nanotechnology although these are larger than true "*nano-*" objects. (Doubtless nanotechnology and MEMS will meet where tiny machines will move or transform molecules.) A hybrid of MEMS technology – **Bio-MEMS** - investigates incorporation of micro-organisms into tiny machines. For instance, the flagella (waving hairs) of bacteria could be harnessed to produce micro-pumps, motors or conveyors if the bacteria can be induced to attach to a specific part of the tiny structure in the correct orientation, and to stay there.

Biotechnology is the application of discoveries across the whole range of the biological sciences. Several decades ago it was mainly concerned with micro-organisms such as bacteria that "eat" toxic wastes and oil spills, or new industrial processes or new bio-pharmaceuticals such as synthetic hormones. More recently, Biotechnology has addressed the building blocks of biology, genetics and cells and their processes at a molecular level: the "machinery of life"[4]. Although ***Organic Machines*** is not a scientific term, it can be used to refer to any intricate organism or natural system - the brain, the liver, a single blood cell; or, the whole biosphere of Earth. The scientific domain of the "organic machine" is **Bio-molecular Machines** and the field of **molecular biology**[5].

Proteomics is the analysis of which portions of a gene "expresses" (is responsible for the formation of) which proteins in the organism hosting that gene. A protein (or group of proteins) responsible for a particular characteristic – such as crimp - may be proven to "turned on" by a particular gene; that is, it is a genetic characteristic. Another characteristic – hardness of the cuticle for example – may be shown to be not genetically related; hence it is phenotypic and may be traceable to feed or other environmental factors. By considering why and how the phenotypic and genetic characteristics are as they are, molecular biology achieves insights into how the follicle and related systems manufactures wool's proteins. It may then derive new biotechnologies that intervene productively in the system.

Genetics is that branch of biology that deals with heredity, especially the mechanisms of hereditary transmission and the variation of inherited characteristics among similar or related organisms. This is the widely known and controversial domain of the human genome project, genetically-modified foods and animals, and human embryo research. **Recombinant DNA** is DNA prepared by transplanting or splicing portions of genes from one species into a host of a different species[6]. Such DNA becomes part of the host's genetic make up and is replicated (is 'recombinant')[7]. Genetics work in Recombinant DNA is often referred to as **Transgenesis**. *Dolly* the sheep is a product of genetics, but **Cloning** a simpler process than transgenesis.

All of these technologies may impact directly or indirectly on the wool industry in the coming decades. The remainder of the paper examines their current and future applications in the wider world, and then the industry specific applications, to deduce the opportunities and threats for wool.

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Current Uses of the New Technologies

> The best material or structure for any particular application will only be found if we understand the relationship between the microscopic and the macroscopic.
>
> - Paul Scherrer Institut, Switzerland

The next two sections highlight examples of the current and future applications of the new technologies in fields outside the wool industry. The purpose is to illustrate the range of applications and to identify possible implications – both positive and negative - for wool.

Built-in Pest Protection (Biotechnology - Transgenesis)

Australia's $1.7B cotton industry has spent $0.25B per year combating the *heliothis* caterpillar and this amount was set to increase as the insect becomes resistant.

Monsanto developed a gene called INGARD® from *Bacillus thuringiensi,* a common soil bacterium. Cotton plants bred with this gene produce a protein in their leaves that is poisonous specifically to *heliothis*. CSIRO developed cotton varieties with the proprietary Monsanto gene. In the first five years of commercial release of INGARD® the usage of *heliothis* pesticides was cut by 50%.

The second half of this story is as important as the first. The danger of delivering this fatal "natural" bacterial protein through this ingenious transgenesis is that if *heliothis* caterpillar developed a strain resistant to the protein, it would become a super-threat.

CSIRO developed cotton varieties with a *second* gene fatal to *heliothis,* also from *Bacillus thuringiensi* and a three-gene variety is envisaged. The chances of a caterpillar having resistance to two (or three) poisons simultaneously – of surviving long enough to have super-survivor children - are infinitesimal. As a further defence against a super-variety, farmers plant sacrificial crops attractive to *heliothis* around the genetically-modified cotton, ensuring that populations thriving in these safe zones will greatly outnumber, and will breed with, any survivors on the cotton, hence keeping the survivor phenotype[8] always diluted.[9]

IMPLICATIONS

Increased productivity in cotton may widen the price gap between wool and cotton goods even further.

This archetypal example of biotech-transgenesis shows both the strategic and tactical aspects of a biotech initiative and underlines the great care taken to avoid downsides, in this case a super-insect.

Transgenic cotton is likely to be less controversial than transgenesis between, say, certain silkworm genes (or spiders) and sheep.

The Spider-Goat (Biotechnology – Transgenesis)

Spider silk has immense tensile strength, far superior to steel. It has been used as the sighting lines in bomb-sights, gun-sights and other sighting instruments for 60 years. Nexia[10], in partnership the US Army Biological Chemical Command, has developed a way of producing spider silk in large quantities. Cells from the mammary glands of dairy cows are genetically modified with specific spider genes to produce the proteins used to make specifically the drag-line silk (not the web silk). These modified mammary cells are introduced to dairy goats and the product, **BioSteel**®, is extracted from the goat milk and spun into a monofilament. Commercially produced it has immediate applications: as finer, stronger medical sutures; for spinning into strong, light, thin, ropes and cables; and for weaving into body armour lighter and stronger than Kevlar.

> *IMPLICATIONS*
>
> **BioSteel**® does not compete directly with wool but this case is a good example of the ingenious possibilities of proteomics and directed research.

The Soy Attack (Biotechnology; Materials science)

Chinese biochemists have produced a new fibre from soybean. *Soybean Protein Fibre* (SPF) is produced by wet spinning soybean residue treated with various enzymes[11]. Promoters say the inputs and outputs of the process are environmentally benign and antibiotic; and that antiphlogistic agents can be added during spinning to gain germ-resistance and ultraviolet-resistance. It is claimed that SPF fabrics are soft and have lustre of raw silk, moisture conductivity of cotton fibre and warmth values of cashmere.[12]

> *IMPLICATIONS*
>
> SPF is a competitor to wool in the same sense as any other "natural" material such as silk or polished cotton.
>
> There may be opportunities for attractive new Wool/SPF blends.
>
> This is an example of biotechnology's ability to produce fibres thought impossible or ludicrous even 10 years ago.

The *Lotus Effect*™ (Nanotechnology; Surface Science)

A bead of dirty water

The **Lotus Effect**™ mimics the *super-hydrophobic* (water-repellent) surfaces of the lotus plant. Water falling on the leaf immediately forms beads and rolls off; collecting any dust as it rolls. A botanist's nanoscale investigation found the lotus can do this because it is coated with hydrophobic wax crystals, but the beading and dust-collection effect is not because the leaf is smooth but because, at <u>nanoscale</u> level, it is quite <u>rough</u>. The crystals are around 1nm in diameter but are laid down as a very uneven surface with only about 3% contact with a water droplet. On a smooth surface, the beads would slide rather than roll and not pick up dirt particles to the same extent. BASF has commercialized these findings in a "lotus-effect" aerosol spray which combines nanoparticles with hydrophobic polymers such as polypropylene, polyethylene and waxes. As it dries, the coating develops the rough nanostructure – it is "self-assembling". The product has immediate application as a water-proof, self-cleaning coating for architectural surfaces.

IMPLICATIONS

This technology is a pathway to intelligent surface coatings of the future.

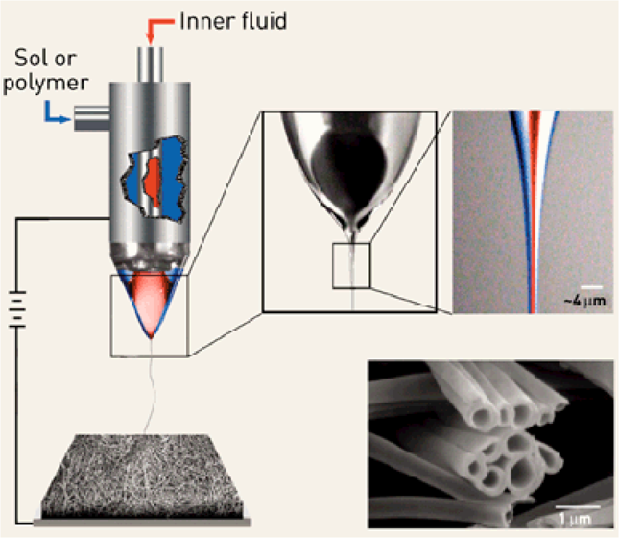
The lotus analogy may provide an answer to the wool cuticle / felting problem. Could the cuticle be coated – not in the present gross processing manner but with nano material that would fill the serration and nothing else, producing enhanced natural wool?

Future Uses of the New Technologies

Hollow Nanofibres (Nanotechnology; Materials Science)

This newly-proven process is ground-breaking and deceptively simple. Two fluids are expelled through nanojets under electrical charge.

> By the injection of two immiscible—or poorly miscible—liquids through a pair of concentric needles to which a high voltage is applied, the liquids emerge from the needles coaxially: a tiny interior stream of one material surrounded by a shell of the other. The shell solidifies around the interior liquid, which serves as a simple template and evaporates once the fibers are collected[13].



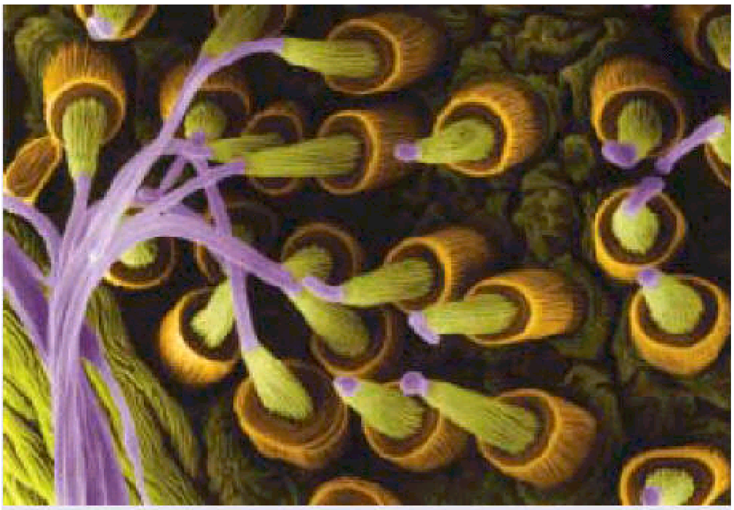
FIBER SPINNING Applying high voltage to a pair of concentric needles used for pumping two immiscible liquids (red and blue at upper left) leads to formation of a two-component liquid cone that elongates into coaxial liquid jets and forms hollow nanofibers. Cut silica nanofibers are shown at bottom right.

IMPLICATIONS

"Synthetic fibres" until now have been extruded solid monofilament. This approach – at nanoscale or larger – promises to produce numerous opportunities in manufactured fibres. Using two or more material streams and/or two or more template streams, and steering the streams electrostatically, a very large range of product is possible. It may be possible to produce slight "natural" crimp in the fibre or figure-of-8 ready-made thread.

Rather just another nano-process, it is likely that this demonstration is a pathway to an <u>entire family</u> of fibre-producing technologies.

The spinneret array of a spider (*below*) may be a vision of the future of synthetic fibre.



Nature in action:
This highly magnified and colour enhanced SEM picture shows silk fibers (purple) emerging continuously from a spider's multiple spinnerettes (green). Nexia seeks to mimic this process. [14]

The process engineer who can now see clearly what spiders do when spinning web, would be wise to mimic this when designing a new generation of bio-textile spinneret arrays. Doubtless each spinneret is angled and turned on or off according to the type of thread required. This insight is only possible through the use of the scanning electron microscope (SEM), a cornerstone tool of the nanotechnologist.

> *IMPLICATIONS*
> The new technologies may impact physical manufacturing processes.

Plastics that Breathe (Nanotechnology)

Work at Paul Scherrer Institute in Switzerland – "Nanoreplication in Polymers" – indicates that there may soon be commercial processes to produce non-woven synthetic textiles with nano-scale textures or nano-scale holes as small as 35nm at 90nm centres[15]. If applied commercially, this will give non-woven textiles the ability to "breathe" at a molecular scale and would open a new array of applications such as coat linings.

> *IMPLICATIONS*
> Possible negative impacts of this nano-production arise from plastics product claiming to "breathe like wool".
>
> A possible opportunity is the capability to integrate wool and breathable plastics to exploit the characteristics of each.

Current Applications for Wool

This section examines the current and future applications of the new technologies within the wool industry, to prompt consideration of the possible opportunities and implications within the time horizon of *Future Woolscapes.* Current applications are categorised according to whether they apply to wool production, wool processing or wool finishing.

Wool Production

The Shrink-proof Sheep (Eugenics, Materials Science)

CSIRO and the Western Australian Department of Agriculture have shown that wool shrinkage (felting) is a heritable trait[16]. 2000 wool samples were submitted to a feltball density test and the results correlated against pedigree information, with corrections for unrelated features such as fibre diameter.

Low-felting wool has significant advantages at all stages in the processing chain and requires less anti-shrinking chemicals allowing cost-savings and less processed, hence better quality, end-product.

Using similar methodology, resistance to dust has also be shown to be a highly heritable trait.

IMPLICATIONS

This discovery may deliver substantial cost-saving in wool production.

Good basic science can still achieve breakthroughs in this day of scanning electron microscopes and molecular biology.

The ability to categorise other traits, such as staple length, as genetic or phenotypic should narrow the field for further helpful research.

Bioclip® – "Natural Wool Harvesting" (Biotech. – proteomics)

"*After 40 years of research, and constant development, Bioclip is now scientific fact.*"[17]
Bioclip® is a recently proven biotechnology solution to "automatic" shearing of sheep which will become commercially available during 2004. Wild sheep breeds naturally drop their wool annually but this trait was bred out of them over thousands of years during domestication. CSIRO isolated the protein that causes the wool to "break", synthesized it and determined the optimum dosage to administer.

The sheep are injected with the protein dose and "boob tube" plastic fishnet material is stretched over their torso. The protein causes the wool to break in a few days but "harvesting" is delayed about a month until the sheep have grown protective new hair. The Bioclip method – including the vaccine, the nets and labour – costs about A$4 to A$5 per head. This seems high compared to the cost of about A$2 per head for shearing but is seen as acceptable when the increased return on the improved clip, ancillary costs of shearing, and the welfare of the sheep is taken into account.

IMPLICATIONS

If there are no long-term ill effects on the sheep, BioClip® seems to be a truly revolutionary development in the Australian wool industry.

It is an example of skilful proteomics and perseverance.

The Test-tube Sheep (Biotechnology – Genetics)

The first genetically-modified (GM) sheep in Australia were born in 1987 with an extra copy of a sheep growth hormone gene engineered by CSIRO. In 2002, CSIRO concluded a three year study of this GM trial with the opinion that "…*although there is little commercial benefit in GM sheep at this stage, there could ultimately be a role but not until exhaustive evaluation is concluded*"[18].

As expected, the GM sheep grew faster and were leaner and larger than normal sheep; some breeds produced more wool, some produced more milk. The unexpected side-effects included diabetes, hooves which required regular trimming, overgrown knuckles, and greater susceptibility to internal parasites.

Matilda

Matilda, Australia's first cloned merino, was produced at South Australian Research and Development Institute (SARDI) in April 2000. She died on 07 Feb 2003 unexpectedly of unknown causes.[19]

Transgenesis and cloning have provided a more accurate tool for exploring desirable wool characteristics but is not simply a matter of choosing that perfect sheep and cloning a multitude. Cloning is a means to an end more than a possible end in itself; it gives insight into what characteristics are genetic and which are "random" characteristics of the individual (phenotypic).[20]

It is virtually impossible for conventional breeding to influence a particular characteristic and only that characteristic – for instance, a breeding program with progeny showing improvement in wool structural proteins may also produce sheep with low disease resistance or other genetic flaws.

SARDI is leading research into how genetics relates to the biological assembly of the wool fibre. By applying the best efforts in transgenesis ("gene-splicing") to results from molecular biology's exploration of the complex structure of wool, SARDI is attempting to account for which genes produce which characteristics.

IMPLICATIONS

Genetics alone will not provide a magic bullet solution for the wool industry.

A thorough understanding of how and why wool is as it is, using the best of science from molecular biology and biochemistry, does provide the certainty of solutions to problems (such as felting).

The time-frame of scientific breakthroughs is uncertain.

Wool Processing

The **Optim®** and **Sportwool™** are well-known Australian technologies and will not be discussed further.[21]

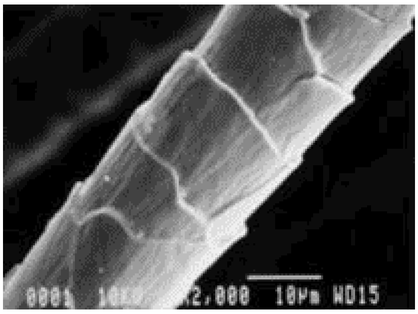
Finland - Washwool® (Materials Science, Biotechnology)

New Finnish high-technology company, Melocoton, has developed an enzyme-based process for finishing wool. **Washwool®** is said to offer a revolution in the use of wool in apparel and textiles by permitting repeated water washing of wool without shrinkage, felting or pilling. Additionally, it eliminates the "prickliness" that some users complain of. It is an environmentally benign protease enzyme process based on natural raw materials and generating completely biodegradable waste products. Global marketing is scheduled to start in 2005.

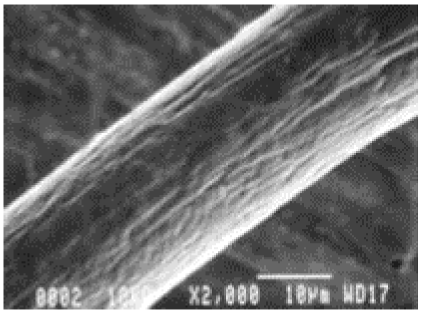
The system was developed with assistance from the Technical Research Centre of Finland, VTT, which is renowned for its expertise in enzyme applications. Risk capital was provided by the Finnish National Technology Agency, TEKES[22].

> *IMPLICATIONS*
> Although licencing costs are not presently available, it is likely that *Washwool®* -- and any similar technologies – will have significant (perhaps immense) impact on the wool apparel market.

A Keratin-degrading Enzyme from Mould (Biotechnology)



Untreated (with scaly cuticle)

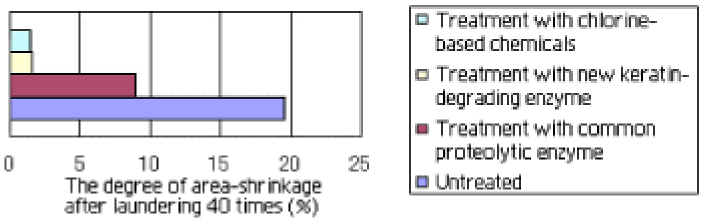


After treatment with new keratin-degrading enzyme (the cuticle has been removed)

Many projects around the world continue to address the shrinkage (felting) property of wool that is caused by entanglement of the fibre cuticles. All approches to date have sought to either (a) mask/cover the cuticle, or (b) remove the cuticle sub-structure entirely. All processes of either type produce some or all of the following downsides:

- chemical wastes that are now seen as environmentally hostile;
- degradation of wool's natural moisture transmission properties;
- degradation of the natural soft touch that is one of wool's selling points;
- reduction in the wool's strength.

Owari Textile Technology Center have isolated a mould occurring in soil that can selectively break down the keratin of the cuticle, leaving the rest of the fibre structure and chemistry unaffected.[23]



> *IMPLICATIONS*
> This is a good example of a clearly-defined problem being solved, seemingly without any downsides, through the application of good biological science.
>
> Whether Australian stakeholders seek licence for processes such as this or develop their own from first principles will be a matter of diligent cost-benefit analysis.

Smart Fabrics and Smart Clothes (Materials Science)

Softswitch - a joint venture between Canesis NZ and Peratec UK

Australian Wool Innovation Ltd (AWI) has already explored "smart textiles" with researchers from Brunel University.[24] The numerous applications generally envisaged range from suits with a keyboard woven into the sleeve to smart doonas (squeeze this corner to open the windows) and are all based on the premise that (soft) electrical switches and wiring can be incorporated into the fabric at the time of manufacture. *Softswitch* developed in New Zealand is a market-ready application of a flexible keyboard that can be carried in a pocket and connected to a notebook computer or mobile phone when needed.[25] Although many other envisaged applications are of marginal use and are more smart-switch than textile, the principle of weaving new functionalities into fabric (or spinning it into thread) at the time of manufacture is important and will be applied in coming decades.

The *Wuxi First Worsted Mill*[26] in China is already producing a range of "smart textiles" for the urban information warrior; in Wuxi's own words:

- Electromagnetic wave-proof worsted fabrics – "*With the social development and people's living standard going up, the modern people inevitably live in an environment congested with all sorts of electromagnetic wave radiations. … Those radiations exert great harm to humans' bodies and consequently cause diseases ranging from headache, weakening eyesight, abnormity of circulation system, diabetes, cancer, malfunction of immune system and disorder of hormone. … Actually, this kind fabrics can effectively shield those electromagnetic waves emitted by the cellular phone, PC and micro-wave oven etc., and ensure people against any radiation pollution."*
- Anti-static worsted fabrics – "*The common friction in daily life can produce static electricity and adhere dust to the surface of the garments. People may feel uncomfortable by clothes sticking on their bodies. Their values of pH, and amount of blood sugar and calcium in urine rise while amount of calcium and Vitamin C in blood fall because of the static electricity More seriously, people will get shocked and the electronic cells will get damaged when the static electric charges on a coat reach to a certain amount."*

Despite the difficult English, it is clear that the market motivation is based on the strongly held beliefs of Eastern medicine about the body's "balance". Since the publication of Linus Pauling on the *orthomolecular* view of living cells[27], the Western and Eastern views have started to converge. It is likely that the demand for "protective" textiles such as this will increase.

Simpler and less controversial applications such as curtains with embedded sensors that open/close in response to ambient light or temperature, and carpets that detect movement across them are applications that will have a market on a simple cost/benefit basis.[28] The key to market success will be whether these developments are led by the textiles industry or the electronics industry and whether industry standards for the edge interfacing of fabrics with circuitry can be established early[29].

IMPLICATIONS

The challenge is to sort novelty applications from enduring products.

The Chinese illustration and the "security carpet" are examples of probable cost-effective, utilitarian products that will impact the wool industry.

Another aspect of "smart" fabrics and textiles is often lost because "technology" is taken to mean something electronic. Some of the most useful future applications may be "smart" clothing that objectively gives an indication of how soiled it is. Dutch researchers investigating strategic environmental assessment methodologies for "Sustainable Households in 2050" insist that textiles and clothing must be investigated within the complete clothes-use cycle – from manufacture, through use / repair / washing or cleaning, to disposal[30]. In this context, how often clothes are actually cleaned is a crucial part of the environmental equation – a million people doing one wash load more or less per year constitutes 50 tonne of raw detergent more or less in the waste disposal system.

clean	**worn**	**soiled**	**launder**

notional "wash-me" indicator [//infos]

Clearly, calibration will be a contentious aspect – "dirty" depends on the user, the use, and the cost of cleaning but solutions will flow if a need forms in the market's mind. One answer may be a "grey scale" incorporated into the clothing label. It is the textile of the label that is smart; presumably it would respond to a protein or other component of human sweat. Analogous to this is smart clothing that can detect hazards in an occupational health and safety environment. Many hazards such as radiation are already monitored using tags but another class of hazard could be usefully monitored if clothing changed colour where splashed with certain chemical types.

IMPLICATIONS

Smart clothing and textiles is in the domain of chemistry and biochemistry as well as electronics. A range of self-indicators using tags of smart textile could offer both a trendy marketing edge and genuine ecological benefit.

These new applications require a different mind-set within the industry and consultation outside the industry if the opportunities are to be identified and exploited.

The Moth-proof Sheep (Biochemistry, Materials Science)

An approach being explored to moth-proof wool, dual purpose reactive dyes, has great promise if proven. In short, the dyes will have a moiety of a pesticide molecule, a half of a "key". When wool treated in this way is ingested by the moth lava – the "first bite" presumably – the moiety is hydrolyzed in the insect gut to release the insecticide.

This approach – and work on plasma treatments to impart insect repellence - are being tested at Department of Apparel, Textiles & Interior Design at Kansas State University but results are not presently available.[31]

IMPLICATIONS

This treatment promises to remove one of the major disadvantages that some consumers perceive and to extend the useful life of consumer textiles and apparel by enhancing insect resistance.

This ingenious biochemical breakthrough could be one of the biggest in the history of wool.

A Hundred Times the Value from Wool (Biotechnology)

Over ten years the New Zealand Wool Research Organisation (WRONZ) - now pursuing all research as Canesis Network Ltd - developed the ***Keratec*** technology which "dissolves" wool and extracts the constituent proteins for use in specialised products such as textile treatment, and cosmetics such as "anti-aging" cremes. The process increases the value of the wool used by "hundreds of times".[32]

> *IMPLICATIONS*
>
> The Australian industry must keep pace with developments across the whole spectrum of new technologies.
>
> There may be opportunities for joint research and joint venturing.
>
> Whilst most scientific progress is evolutionary, some developments in the time horizon of *Future Woolscapes* may be revolutionary.

Wool Finishing

Bushfire Curtains (Materials Science)

AWI collaborated with a private company to develop a new product meeting a clear and present marketplace need. For decades CSIRO have warned that most homes in bushfire areas burn from the *inside* – radiant heat breaks the windows and ignites furnishings inside the house. Permanent fire shutters are an answer but are quite expensive.

AWI developed a non-woven wool curtain treated with heat cured fire retardant. When fire is approaching, the curtain can be secured by metal rings which attach to pre-installed hooks around the windows and doors. CSIRO tests show the curtain exceeds the Australian Bush Fire Code of withstanding 10 kilowatts of direct radiant heat for 10 minutes.[33]

> *IMPLICATIONS*
>
> This is an example of meeting a need by matching one of wool's properties – in this case its fire-resistance – precisely to an application.
>
> The potential market is large and lucrative.

Threats from New Technologies

The threats posed by new technologies may emerge for several reasons:

- Because competing materials gain a significant competitive advantage
- Because wool fails to exploit the potential of the new technologies
- Because wool growers do not meet the expectations of clients and consumers in their own value chain
- Because consumers develop an aversion to any product or process in which scientists are perceived to interfere with nature. This is a significant threat. Reflected in the "clean and green" slogan, it could develop momentum very rapidly if there is a major setback in any of the branches of science above.

This section focuses on the threats from competing materials.

Age-Old Alternatives Steal an Advantage

Third-world fibres are now turning to first-world technologies and may offer some degree of competition to wool in all traditional niches except ultra-fine apparel wool.

Jute

Jute is a plant fibre with linen-like qualities. The literature often confounds jute (various *Corchorus* species[34]) and hemp (Cannabis sativa); and "jute" in some contexts is used as a euphemism for hemp. Jute accepts dyes well and is highly durable; the range of modern applications of the processed product is impressive and growing ...

Jute products (Bangladesh)

"***Jute blankets**: Blankets produced from jute are strong and warm. They are not affected by moths, and cheaper than cotton, woollen or synthetic blankets.*
***Novotex Fabrics**: The fabrics are made from jute and cotton. Novotex fabrics are strong, durable, light- and colour fast, attractive and cheap. They are suitable for apparels, upholstery, school bags, travel bags.*
***Wool-substitute soft jute yarn**: Jute yarn is processed to have a wool-like look and feel. It can be used to make sweaters, cardigan, scarves, socks -- it is warmer and cheaper than wool.*

***Fireproof jute fabrics**: These fabrics meet the requirements of flame-proof fabrics according to international standards and are suitable for fire proofing and insulation. **Jute geo-textiles**: These textiles are flexible, foldable, not very biodegradable, and water-resistant." - Bangladesh Jute Research Institute* [35]

Hemp

Both the EU[36] and Canada have active research programmes in higher value uses of hemp. Even scientific objectivity cannot constrain the Special Crops project of *Agriculture and Agri-Food Canada* from glowing claims about hemp:

> Hemp's remarkable advantages are hard to beat: it thrives without herbicides, it reinvigorates the soil, it requires less water than cotton, it matures in three to four months, and it can yield four times as much paper per acre as trees. Hemp can be used to create building materials that are twice as strong as wood and concrete, textile fiber that is stronger than cotton, better oil and paint than petroleum, clean-burning diesel fuel, and biodegradable plastics. In addition, it can produce more digestible protein per acre than any other food source. These advantages are in tune with the environmental and health preferences of today's North American public. The growing curiosity of consumers, the interest shown by farmers and processors, and Canada's excellent growing conditions for industrial hemp allow optimistic views for its future.[37]

Shanxi Greenland Textiles[38] in Shanxi Province China is the largest hemp textile producer in China, probably in the world. The illustration conveys quite well a *new, soft, pretty* image that would be the envy of any marketer. Clearly, the enthusiasm in Europe and Canada for hemp and proven Chinese textile know-how could produce a well-priced competitor to wool in, at very least, the mid-range mid-weight knitwear market.

China is not renowned for ecologically-friendly manufacturing processes; however current research in Europe will probably advance hemp's green associations[39]. The Dutch Agri-business organisation ATO produced research results in January 2004 in "HEMP-sys, an integrated quality chain for textile hemp" at an EU Textiles Technology conference[40]. Papers on "Enzymatic modification of hemp fibres for sustainable production of high quality materials" and "Integrated cDNA microarray and spectroscopic analysis during hemp plant development" will be presented in June 2004 at the 3rd International Conference on Textile Biotechnology[41]

> *IMPLICATIONS*
>
> Hemp and jute have developed from the domains of rough utilitarian fibres and the hobbyist fanatic to be the first new natural fine apparel fibre in 4,000 years, with the help of modern Materials Science and Biotechnology (mainly enzyme science).
>
> Hemp may directly compete with wool in mid-weight knitwear and in warmth apparel and textiles.
>
> The wool industry should systematically monitor the major potential competitors.

Kenaf

Along with hemp, jute, and other alternative crops there is worldwide interest in kenaf (Hibiscus cannabinus), especially in the enhancement of aesthetics properties for a wider range of products through bleaching, dyeing, and finishing, usually using microbiological analysis and new ecologically-safe bio-processing often using enzymes.

> *IMPLICATIONS*
>
> Although it does not seem kenaf has any chance of approaching the potentialities of jute or hemp as a direct competitor with wool, again it is worth monitoring developments.

New-Age Naturalism Steals an Advantage

Henry Ford was dedicated to commercializing plant-based alternatives to petroleum. He wore suits and ties made from soya fibre (see discussion of *SPF* elsewhere) and in 1941 launched a "concept car" with a plastic body of entirely plant origin. The cost of these phyto-plastics ensured that this remained just a concept. Now, biotechnology and other factors are highly conducive to a revolution in new plant-based products over the coming decades:

- The continuing success of green politics in Europe and unabated lobbying by an increasingly influential minority of the US electorate;
- International pressure for universal acceptance of the Kyoto protocol;
- New political sensitivities towards international oil supply arrangements;
- The sixty years of development in plant bio-technology since Henry Ford.

Supporting this contention is the fact that corporations renowned for a view to future – such as DuPont Dow Elastomers and Dow AgroSciences – are now turning their high technology resources to plant-based products. In 2002 Cargill Dow registered *NatureWorks*® as a generic fibre[42]. This first new fibre of the 21st century is polylactide (PLA), derived from sugars in corn or sugar beets and other sources. Cargill Dow says that PLA "*combines the most desired characteristics of natural fibers such as wool, cotton and silk, as well as conventional synthetics*."[43]

This and other initiatives indicate that the age of **agriplastics / phytoplastics** has begun under perfect conditions - given ecological sensitivities, rising petrochemical costs and developments in biotechnology. This will have profound effects on the world clothing and textile markets in coming decades. From Bangladesh to Europe to USA there is intense investigation into the use of jute and hemp (and other *bast* fibres) and a range of crop *residues*, agricultural *by-products*, and post-consumer *wastes* in several modalities:

- Use of these sustainable crops and presently wasted agri-residues as **displacements** for petroleum-based polymers, and the processing of these using new technologies to broaden their range of end-uses;
- Establishing bio-polymer and other bio-material processes that can accept substantial inputs of **consumer waste**[44];
- Once established, the same agri-processing industries can produce a large range of products apart from fibres - films, plastics, composites, resins, finishing agents, enzymes (for use in other processes), and many of the functional agents for textile processing that are presently derived from petrochemicals.

It is not jute, nor hemp nor kenaf that will lead any revolution. Rather, it is the current re-thinking of bio-processing under influence of the drivers mentioned that will, to varying degrees, in varying time-frames, lead to "bio-refineries", conceptually similar to petroleum refineries but clean, green and socially meritorious. Fine Hemp (or jute or new agri-composites) will be just one product of many from such "refineries". The products are likely to have better fibre/textile properties than ever before at a lower cost than the craft-scale experiments have achieved to date.

> *IMPLICATIONS*
> In this newer, better, greener context, wool will be expensive and will have no choice but stress it too has an impeccable eco-pedigree, but is not "artificial" like these new fangled fibres.

Return of the Synthetics

Cellulose is the most common organic compound on earth. In its many forms and structures it is a component of the cell wall of all green plants, occurring in almost a pure form (91%) as cotton, and in high yields from other sources - hemp (77%) and wood (around 60%). It is a source of familiar "synthetics" such as cellophane, acetate (the base for movie and still film), rayon, and triacetate. It is non-toxic but cannot be digested by enzymes in the human gut.

A world-wide network of scientists is re-examining cellulose in the light of the new technologies. A scientist at the University of Texas proposes several branches of investigation[45]:

- **New Sources** Genetically re-engineering of cellulose biosynthesis in algae so that super-salty swamps in any region with good sun-light could be used to produce "*perfectly good cellulose*". "*The scale-up of this prospect would suggest that these new resources could even supplant existing resources, including trees and cotton crops*"
- **Better Cellulose** Genetically engineering existing cellulose crops can make them more productive. In addition, the bio-molecular structure of the cellulose could render a "*dramatic impact on the strength of common materials such as paper, wood, and textiles*".
- **Cellulose Refineries** By adding to the already immense body of knowledge about cellulose, processes could be designed to produce cellulose of any given form from ecologically acceptable inputs - *much like the refining of petroleum products, and used to produce plastics and synthetic polymers. Such cellulose refineries may raise the standards of product quality to such a degree that we would not have to rely on synthetic polymers for many of our needs. Maintaining a natural product with biodegradable properties is also of great benefit when we consider future directions.*

Underpinning all these initiatives is the belief that *a return to basics in trying to understand the truly complex and integrated systems of polymer biosynthesis will greatly help us in the design of future polymer- generating approaches, whether native or synthetic*[46]. Although this begs the question of what is "natural", the point is that more can be learned from further study of the most common natural polymer, cellulose, than from investment in further plastics from petro-chemical sources.

IMPLICATIONS

It is highly likely there will be breakthroughs within 25 years in the production of phyto-fibres and / or the type of "cellulose refineries" envisaged will appear.

These clean, green factories may be able to make cellulosic polymers that are well suited, using then-mature electro-spinning technologies, to producing fibres far more sophisticated than "synthetics" such as rayon.

Opportunities for Wool

The inherent qualities of wool afford it significant advantages now and these will not change over time. Other competitors will continue to use wool and its qualities as their benchmarks. There are opportunities to further enhance the qualities of wool and the utility of the products made from it.

However wool also has some inherent disadvantages – notably a tendency to shrink, susceptibility to certain insects and a perception that it is “prickly”. The opportunity is to apply the new technologies to overcome these disadvantages. Whilst the capability to do this has already been demonstrated, the improvements will not reach their full potential until they are inexpensive and can be universally applied to all the purposes of wool.

There are further opportunities to combine wool with other (possibly new) materials.

Plasma Treatment of Wool (Materials Science, Nano-Science)

Plasma[47] technology has been used for some years to improve the surface properties of synthetic polymers, to lacerate the perfect surface to improve dyeing and wetting properties[48]. The use of plasma – air or another gas ionized by high voltage -- to improve the surface properties of wool has been investigated only more recently[49]. It is motivated by the several downsides of chemical treatments of wool.

An experiment at Hong Kong Institute of Textiles and Clothing, written up in March 2004, indicates that *low-temperature plasma (LTP)* treatment of wool is promising[50]. The breaking load of the wool fabric was increased by 18%-24% (weft-warp) but tearing resistance was lower, possibly due to the higher friction between threads. Importantly, the shrinkage (dimensional change due to felting) of the LTP-treated fabric was *one-tenth* that of untreated fabric. Wool without the treatment did <u>not</u> meet the maximum shrinkage requirements of ASTM D3780-95, D4155-95 but LTP-treated fabric *meets both standards*[51].

> *IMPLICATIONS*
>
> Plasma treatment for wool is already a research priority in Australia. The technology offers immense value to the wool industry in treating felting and other undesirable characteristics. It can only be performed satisfactorily in concert with nano-inspection of molecular changes wrought by various plasma recipes.

Green Outputs / Green Inputs (Chemistry)

> "Almost half the wool we produce would meet the criteria for low pesticide residues so we have a flying start.... [It] also requires lower levels of chemicals to be used in all processing stages of scouring, spinning, dyeing and finishing.... At the end of the day, most of the processing criteria are based on decreasing water pollution which is where most of the environmental impacts are of wool production...." – Dr Ian Russell, CSIRO Textile and Fibre Technology[52]

The EU has a voluntary labelling system - the Eco-Label - that certifies a product has met stringent ecological standards *throughout its entire production chain*.

Many traditional wool scouring and finishing processes are renowned for undesirable environmental impacts and are being phased out or are unlawful in many parts of the world. The fleece as shorn is also subject to these standards.

> *IMPLICATIONS*
>
> The EU Eco-label is a portent of standards to come in most markets.
>
> All links in the value chain – including sheep husbandry will increasingly need to conform to these standards.
>
> Australia is well placed to extend its "clean, green" image to wool.

Back to Basics ("Basic Science")

After a moratorium of some 10 years, CSIRO – with funds from AWI – is returning to basic research[53] into wool. Following a recent decision by AWI to invest 25% of R&D funds into strategic (long-term) research, collaborative research with the potential to link the world's best wool expertise has re-commenced. This may be applied to address fundamental problems like those below.[54].

- The ***F-layer*** is the complex outer layer of wool comprising the cuticle and a layer of fatty acids. This layer gives wool its water repellence and soft hand, but it is the entanglement of the cuticles that cause felting (shrinkage). Removing the cuticle layer improves shrinking properties but leaves the fibre damaged and harsher to the touch. This age-old dilemma can only be resolved by basic scientific investigation of the F-layer. One avenue of research will explore enzymes that split fatty acids from proteins.
- The **rapid yellowing** of wool in sunlight was first identified as a scientific problem in 1956 but there has yet been no complete account of the phenomenon, or a remedy. If this round of research can provide an answer it will remove the severe marketing limitations on white and pastel-coloured wools.
- The **tensile strength** of wool fibre is substantially inferior to other fibres such as cotton. This means that it must be spun at lower speed with frequent hold-ups due to breakage and finished wool products are weaker than other textiles. Some of this weakness is due to removal of the cuticle layer during shrink-proofing. Much disparate information on wool strength has been collected over many years. This round of research will document what is known to date and will seek a comprehensive account of how wool products can be made stronger.

> *IMPLICATIONS*
>
> There is a major opportunity to resume fundamental research into wool's eternal difficulties.
>
> AWI's funding initiative coincides with exciting new work in enzyme and plasma treatments from Finland to Japan, and with tools and technologies not previously available.
>
> It will be a test of the industry's resolve to persevere with the strategic investment in basic science when short-term fixes beckon.
>
> The industry needs an agreed process and set of criteria for determining research priorities.

The Limits of Nature, and Logic (Biotechnology)

Enzymes are biological catalysts that enable or control reactions between molecules. Without enzymes, organisms, and life, would not exist.

Enzymes are made from combinations of *amino acids*. This is important because more than 10^{100} average-sized synthetic enzymes could be made from the 20 amino acids that occur in nature, whereas only around 10^{14} enzymes are actually present in the entire biosphere. As it is also possible to synthesize more than these 20 natural amino acids, the number of possible but nonexistent enzymes – and the processes to test them in - is not infinite but is a very, very large number.

Much of biotechnology is concerned with understanding the role of natural enzymes and exploring the possibilities of new enzymes in natural processes. Much research is directed by goals and knowledge but many breakthroughs are the results of laborious trial-and-error permutation and combination of enzymes and processes. For this reason, work in progress is often discussed in the most generic terms and intermediate results are treated with the greatest commercial secrecy. That "breakthrough" may always be just a day away and it may have taken a $billion to discover that "unknown" enzyme *xyz* may be the answer.

> *IMPLICATIONS*
>
> It is *logically* possible to produce a genetic modification for sheep to reliably produce 9-micron low-crimp long staple wool without deleterious or inhumane

side-effects. To succeed in this requires as much luck as skill; and no research organisation is likely to declare when it is "very close".

Alternatively, it is *logically* possible that an Australian scientist tomorrow will discover a yet unknown truth about breeding and wool chemistry through the difficult art of proteomics. Again, this is as much craft as art and such work can succeed only in an environment that encourages **basic** research.

TIME-LINE for the Technologies mentioned

Conceptual - An end-goal and a sketch of the research necessary has been defined.
Research - Research is actively being pursued.
Proven - The science has been proven but the process may or may not be commercially viable.
Now - The process has been commercialised.

Current Uses	
Built-in Pest Protection (Biotechnology - Transgenesis)	Now
The Spider-Goat (Biotechnology - Transgenesis)	Now
The Soy Attack (Biotechnology; Materials science)	Now
The *Lotus Effect*™ (Nanotechnology; Surface Science)	Now
Future Uses	
Hollow Nanofibres (Nanotechnology; Materials Science)	Proven
Plastics that Breathe (Nanotechnology)	Research (5 years)
Current Applications for Wool	
The Shrink-proof Sheep (Eugenics, Materials Science)	Research (5 years)
Bioclip® - "Natural Wool Harvesting" (Biotech. - proteomics)	Now
The Test-tube Sheep (Biotechnology - Genetics)	Research (5 - 7 years)
Finland - Washwool® (Materials Science, Biotechnology)	Now
A Keratin-degrading Enzyme from Mould (Biotechnology)	Proven
Smart Fabrics and Smart Clothes (Materials Science)	Research and Proven examples
The Moth-proof Sheep (Biochemistry, Materials Science)	Research
A Hundred Times the Value from Wool (Biotechnology)	Now
Bushfire Curtains (Materials Science)	Now
Threats from New Technologies	
Jute	Proven processes
Hemp	Proven; Research on Upscaling commenced
Kenaf	- no data -
New-Age Naturalism Steals an Advantage	Conceptual; most component processes proven
Return of the Synthetics	Conceptual
Opportunities for Wool	
Plasma Treatment of Wool (Materials Science, Nano-Science)	Proven
Green Outputs / Green Inputs (Chemistry)	Research
Back to Basics ("Basic Science")	Methodology
The Limits of Nature, and Logic (Biotechnology)	Theoretical limits

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Conclusions and Implications

Technologies

The new technologies are still in their infancy but the impacts are being felt across many spheres of society including in fibres and textiles. As the examples in this paper attest, there have already been some incremental changes and some radical innovations. However, what appear to be exciting steps are probably just precursors of the future possibilities. Even more dramatic developments wait to be realized when knowledge and technical competence grow in these relatively new fields.

In the 5-10 year time frame the technologies with the most potential are genetics and molecular biology - working together. In the mid term (10-15 years) the major breakthrough is likely to be in biotechnology with the commissioning of integrated agro-chemical refineries ("eco-converters"). Towards the end of the period under review nano-sciences should mature and the applications (such as extracting carbon for nano-built objects from airborne pollution) have profound implications.

However it is important to remember that the technology is neutral. It may pose threats to one industry whilst opening amazing opportunities for another. The advantages are most likely to accrue to those who plan ahead.

The Wider Environment

Applications of the new technologies outside the wool industry are useful for two purposes. Firstly because they indicate the potentialities and possible pathways to the future. Work with cellulose fibres and protein fibres other than wool is of particular note. Secondly, and more specifically, they may illustrate the broad possibilities for apparel, textiles and industrial uses of fibres. Some of these developments may be directly transferable to wool.

Incremental improvements can occur anywhere along an industry's value chain. Traditional competitors need to be monitored, lest they can reduce production costs dramatically or make major advances in quality that afford an advantage in the market-place.

New competitors may emerge. Those that warrant particular attention are the ones that exploit a "natural" tag, that have demonstrably eco-friendly production processes and that legitimately claim some of the same qualities as wool. In an extreme case, if a new fibre possessed all the qualities of wool and was significantly cheaper, it could spell the end of the wool industry. This is improbable, but not impossible within the time horizon of this study.

Consumer acceptance is a major issue. The consumer of the future will apply a revised set of criteria to purchasing decisions. These are the subject of a separate paper, but suffice to say eco-credentials (at every stage of production, processing, finishing and recycling) will be very high on the list, and will contribute to new interpretations of quality and value.

Wool

What should be the response of the wool industry?

We start from the basis that wool fibre has an enviable reputation and established uses, including very specific niche markets. The industry should continue to exploit these unique features and natural advantages, but not rest on its laurels. Attention should be directed to every link in the wool value chain and to the underpinning science and technologies. Where appropriate, the industry should look to apply both traditional science and the new technologies for several purposes: to improve the inputs, to reduce costs, to redesign processes, to enhance products, and to "engineer" out the less desirable qualities of wool.

Further, the industry should monitor developments in the new technologies and in other fields and industries, pro-actively seeking possibilities of partnering and joint venturing, as well as applications that can be directly applied along its own value chain. Of course, any enhancements or improvements must be done within the context of what is sustainable and acceptable to the environmentally-aware public.

Implications

It behoves any entity that wishes to ensure its long-term survival to develop a coherent and agreed strategic view of its future environment and how the new technologies may impact it.

Radical changes to one's own value chain or to that of a competitor do not occur in isolation. The innovation process itself requires a series of steps that can be detected and anticipated. The implementation – especially in the production phase – requires major changes, for example to the factory, the machinery, the training of staff. Further downstream, strong signals can be noted in new patterns of marketing and distribution.

These imperatives suggest the need for a systematic scanning program to provide early warning of indicators of major change in the marketspace.

Concurrently, the industry that is going to best exploit the opportunities presented by technology needs a framework and set of criteria for determining research priorities and allocating funding across a myriad of competing claims.

Closing Comment

Our assessment is that we shall witness a major paradigm shift within the 25 year time horizon of this study, as the world moves into a completely new bio-molecular era. The impacts will be at least equal to those of the IT revolution. To survive the transition, the wool industry needs:

- An agreed strategic outlook
- A program for monitoring its environment and the new technologies, and
- A framework for determining research priorities.

With these, the industry would be well equipped to counter the threats and exploit the opportunities that lie ahead.

*"**Where observation is concerned,***
***chance favours only the prepared mind**."*

- Louis Pasteur

Produced by

Ian Ferguson & Assoc P/L
ABN 42 055 778 633
Futures Studies & Scenario Planning
+61 7 3366 7748
ifa@bigpond.net.au
http://imaginativefutures.com

Information Access //infos
ABN 65 485 109 867
Open source intelligence
+61 7 3368 3886
infos@mpx.com.au
http://meta2.com/infos/

References

The full list of sources, Centres of Excellence and portals referred to in this paper, with active web hyperlinks, is on the CD accompanying this paper.

Notes

[1] The Deutsches Wollforschungsinstitute (DWI; **German Wool Research Institute**) at the **Aachen University** Inc. is a modern research facility with a strong focus on state-of-the-art materials. DWI is linked to the Aachen University via the Chair of Textile Chemistry and Macromolecular Chemistry. **http://www.dwi.rwth-aachen.de**

[2] A good listing of the hundreds of topics in Materials Science is posted by Indian Institute of Technology, Kharagpur

[3] *MEMS devices are machines so small they cannot be seen by the unaided human eye. With gears no bigger than a grain of pollen, they range in size from micrometers to a millimeter. MEMS combine electrical and mechanical components into an integrated micro device or systems that can function individually or in groups to sense, control and actuate larger devices* "Researcher Makes Mutant Bacteria Become Microscopic Motors", Small Times, 04 Feb 2003 http://www.smalltimes.com/document_display.cfm?document_id=5431

[4] An early definition by the European Federation of Biotechnology (1981): Integrated use of Biochemistry, Microbiology and Chemical Engineering in order to achieve the technological application of the capacities of microbes and cultured tissue cells.. – contrasted with a more recent one indicates the changing emphasis …… a set of biological techniques developed through basic research and now applied to research and product development. In particular, biotechnology refers to the use by industry of recombinant DNA, cell fusion, and new bioprocessing techniques. - Oak Ridge National Laboratory [home of the Human Genome project]

[5] "The branch of biology that deals with the formation, structure, and function of macromolecules essential to life, such as nucleic acids and proteins, and especially with their role in cell replication and the transmission of genetic information."

[6] *Recombinant DNA refers to DNA which has been altered by joining genetic material from two different sources. It usually involves putting a gene from one organism into the genome of a different organism, generally of a different species*. – Bioethics, University of Pennsylvania www.med.upenn.edu/bioethic/wol/glossary.shtml

[7] recombinant DNA - "Genetically engineered DNA prepared by transplanting or splicing genes from one species into the cells of a host organism of a different species. Such DNA becomes part of the host's genetic makeup and is replicated."

[8] phenotype / phenotypic - "The observable physical or biochemical characteristics of an organism, as determined by both genetic makeup and environmental influences." If two otherwise "identical" animals exhibit different characteristics under different conditions, the differences are said to be *phenotypic*.

[9] see http://genetech.csiro.au/research/index.htm

[10] Nexia 2001 *Annual Report* http://www.nexiabiotech.com/pdf/2001 - Annual Report - English.pdf, further good descriptions of the process are at http://www.wondu.com/Newsletter_3_1_2002.htm and http://news.bbc.co.uk/1/hi/sci/tech/889951.stm

[11] enzyme – "Any of numerous proteins or conjugated proteins produced by living organisms and functioning as biochemical catalysts"

[12] SPF seems to owe its development to the China Academy of Engineering. A good discussion of SPF (and other new phtyo-fibres) is at http://www.bharattextile.com/products/prod_02.php

[13] "Hollow Nanofibers in a Single Step", *Chemical and Engineering News*, 26 April 2004 (82:17) p. 6 ff." http://pubs.acs.org/cen/news/8217/8217notw1.html

[14] *Nexia 2001 Annual Report* http://www.nexiabiotech.com/pdf/2001 - Annual Report - English.pdf [SEM=Scanning Electron Microscope]

[15] Paul Scherrer Institut, Switzerland http://www.psi.ch/index_e_new_mat.shtml; see http://www.snf.ch/nfp/nfp36/progress/schift.html about naon-lithography

[16] CSIRO, "Shrink-proof sheep", Media Release - Ref 2003/72 - 02 May 2003 http://www.csiro.au/index.asp?type=mediaRelease&id=Pr45shrinkproof&xml=relatedMediaReleases;count=100;start=0&style=mediaRelease

[17] Landline, Australian Broadcasting Corp, "Bioclip presents new era in wool harvesting", 23 November 2003 http://www.abc.net.au/landline/stories/s990785.htm

[18] CSIRO, "GM sheep grow bigger, produce more milk and wool ", Press Release 2002/234, 22 November 2002 http://www.csiro.au/index.asp?type=mediaRelease&id=prgmsheep&style=mediaRelease

[19] http://www.sardi.sa.gov.au/pages/showcase/media_releases/2000/matilda.htm:sectID=83&tempID=27 for Matilda's death notice see http://www.theage.com.au/articles/2003/02/07/1044498961733.html

[20] for highly informative account of this see "Wool Biology and Wool Follicle Initiation" http://www.sardi.sa.gov.au/pages/livestock/mw/ip/wool_biology.htm:sectID=519&tempID=120

[21] Optim: http://www.tft.csiro.au/achievements/optim.html Sportswool: http://www.sportwool.com

[22] http://www.melocoton.fi and http://www.hightechfinland.com/2004/healthcarelife/melocoton.html

[23] K. Sasaki, President, Senshoku Keizai Shimbun Co Ltd, *The three faces of technology in the future: Recent trends in the textile dyeing and printing industries in Japan* http://textileinfo.com/en/tech/three/04_1.html

[24] AWI Innovation Radio, "Smart Textiles", 22 May 2003; http://www.wool.com.au/awi/home.nsf/alldocs/rwp6690b4cd18493c0eca256d2e00082e60?opendocument&expand=2.4&

[25] "*The development of a more flexible polymer has enabled new functionality, such as flexible, washable switches that can be activated by finger pressure, and flexible pressure sensors that are integrated into traditional textile fabrics*." http://www.softswitch.co.uk

[26] For full descriptions of these and others in the *Wuxi* range see http://www.wxyimao.com/jianjie-e.htm

[27] Linus Carl Pauling (1901 – 1994) won the 1954 Nobel Prize for Chemistry for work on chemical bonding. This work was the basis for progress in describing the structure and shape of the complex molecules of living tissues. In 1968 he coined the term "orthomolecular" in describing the theoretical foundations for what was later to become a specialty within complementary medicine. See *Britannica*, and web-site of Australasian College of Nutritional and Environmental Medicine http://www.acnem.org/

[28] The security carpet: The additional cost at time of manufacture (together with the simple interface along two edges) would far outweigh the cost of retro-fitted pressure mats and would replace the need for space monitoring and movement detection sensors.

[29] The electronics industry is genetically incapable of agreeing on standards at the start of any innovation. The textiles industry may greatly assist in development of smart textiles as a new class of product by establishing good ISO standards early and sticking by them.

[30] Remke M. Bras-Klapwijk* and J. Marjolijn C. Knot (Delft Univ of Technology), "Strategic Environmental Assessment for Sustainable Households in 2050: Illustrated for Clothing", *Sustainable Development* 9, 109–118 (2001)

[31] USDA "New Technologies For The Utilization Of Textile Materials" http://msa.ars.usda.gov/la/srrc/csrees/multistate.htm

[32] Announcement to New Zealand Stock Exchange 19 May, 2004 http://www.nzx.com/market/market_announcements/by_company?id=100340 and *Dominion Post*, 14 May 2004 http://www.stuff.co.nz/stuff/0,2106,2906802a13,00.html

[33] AWI Innovation Radio, 6 November 2003 http://www.wool.com.au/awi/home.nsf/AllDocs/RWP4BCF2E4CC689517BCA256DD6000394A1?OpenDocument&Expand=2.4&

[34] *Corchorus Cunninghamii* ("Native Jute", "Cunningham's Jute") is an Australian endangered species once native to rainforest margins from Brisbane to Lismore. If this species were ever found suitable for commercial use and saved by an entrepreneur it could become a source of boutique fibre in the King Island Brie tradition.

[35] Bangladesh Jute Research Institute http://www.bangladeshgov.org/bjri/products.htm

[36] "Hemp for Europe - manufacturing and production systems", Project *FAIR-CT95-0396* http://www.nf-2000.org/secure/Fair/R0396.htm

[37] Agriculture and Agri-Food Canada, "Canada's Industrial Hemp Industry", December 2003 http://www.agr.gc.ca/misb/spcrops/sc-cs_e.php?page=hemp-chanvre

[38] Shanxi Greenland Textiles http://www.greenlandhemp.com/eindex.htm

[39] ATO (Agrotechnological Research Institute), Netherlands, Annual Report http://www.agrotechnologyandfood.wur.nl/groups/ATO/AnnualReport2002.pdf

[40] Jan van Dam, Agrotechnology and Food Innovations, Div Biobased Products, Wageningen, Netherlands,"HEMP-sys, an integrated quality chain for textile hemp", COST847 Belfast January 2004.

[41] Holger Fischer, "Enzymatic modification of hemp fibres for sustainable production of high quality materials"; Rudolf W Kessler, "Integrated cDNA microarray and spectroscopic analysis during hemp plant development", 3rd International Conference on Textile Biotechnology, Graz, Austria, 13-16 June 2004 http://www.INTB.org

[42] see http://www.utexas.edu/centers/nfic/NewCenNews/archives/2002/May.2002.ncn.htm

[43] "FTC Oks Cargill Dow Cotton Competitor", Cotton Grower, March 2002, http://www.utexas.edu/centers/nfic/NewCenNews/archives/2002/May.2002.ncn.htm

[44] [as EndNote: The "rag-bag" will become a more substantial recycling stream than present paper recycling systems – old clothes will return, reborn as rugs, geotextiles, perhaps even as clothes.]

[45] R. Malcolm Brown, Jr (Molecular Genetics and Microbiology, Univ of Texas), "Cellulose Structure and Biosynthesis: What is in Store for the 21st Century?", *Journal of Polymer Science: Part A: Polymer Chemistry*, vol. 42 (2004), pp. 487 – 495

[46] This and other quotes on cellulose are R. Malcolm Brown, op. cit.

[47] Plasma is the fourth state of matter; along with solid, liquid and gas. Plasma is any gas heated to sufficiently high temperatures that the atoms ionize into negative electrons and positive ions of the atomic nucleus. In this state the gas may conduct electrical current. Lightning and the Aurora Borealis are plasma phenomena. 99% of matter in Universe is plasma.

More than 99% of matter in the universe exists as plasma, including stars, lightning, and the Aurora Borealis.

[48] See for instance Institute of Fibre Materials Science, Tampere Univ of Technology, Finland http://www.tut.fi particularly *PlasmaFab* http://www.tut.fi/units/ms/teva/plasmafab/index.html

[49] Research into plasma treatment of wool is one focus of Deutsches Wollforschungsinstitute (DWI; German Wool Research Institute) http://www.dwi.rwth-aachen.de

[50] Kan Chi-wai, Chan Kwong and Marcus Yuen Chun-wah (Institute of Textiles and Clothing, Hong Kong Polytechnic University), "The Possibility Of Low-Temperature Plasma Treated Wool Fabric For Industrial Use", AUTEX Research Journal [Association of Universities for Textiles], 4:1 (March 2004). The treatment is document as "*A glow discharge generator (Showa Co. Ltd., Japan) was used for the low-temperature plasma treatment of the wool fabric with the use of oxygen gas. The discharge power and system pressure were adjusted to 80W and 10 Pa respectively, and the duration of treatment was 5 minutes. After the LTP treatment, the LTP-treated wool fabric was conditioned according to ASTM D1776 [8] prior to use.*"

[51] ASTM D3780-95 - *Standard performance specification for men's and boys' woven dress suit fabrics and woven sportswear jacket, slack, and trouser fabrics*; ASTM D4155-95: *Standard performance specification for women's and girls' woven sportswear, shorts, slacks, and suiting fabrics*

[52] ABC, "Green Australian wool for Europe", *News in Science*, 13 June 2001 http://www.abc.net.au/science/news/stories/s311669.htm

[53] See OECD "Main Science and Technology Indicators", and Dept of Education Science & Training, "National Research Priorities :The Australian Research System" http://www.dest.gov.au/priorities/pubs/issues_paper/4.htm
Australian Bureau of Statistics definitions: ***R&D*** *is defined in accordance with the OECD standard as comprising 'creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications'.* ***Basic research*** *-- Experimental and theoretical work undertaken primarily to acquire new knowledge without a specific application in view. It consists of pure basic research and strategic basic research. Pure basic research is carried out without looking for long-term benefits other than the advancement of knowledge. Strategic basic research is directed into specified broad areas in the expectation of useful discoveries. It provides the broad base of knowledge for the solution of recognised practical problems.* [our emphasis]

http://www.abs.gov.au/Ausstats/abs@.nsf/Lookup/8076A6F12125CB53CA256D97002C8656

[54] AWI Innovation Radio, "CSIRO Basic Wool Research", 5 February 2003 http://www.wool.com.au/awi/home.nsf/AllDocs/RWP65206B1D6CBD99DBCA256CC40012D925?OpenDocument&Expand=2.4&

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