New Synthetic Fibers Come from Natural Sources

By Maria C. Thiry, Features Editor

In the beginning, textile fibers came from the natural world: animal skins, hair, and wool; silk from silkworms; and plants like flax, cotton, and hemp. For centuries, all textiles came from fibers that were harvested from a plant, animal, or insect. Then, at the beginning of the 20th century, people discovered that they could create textile fibers of their own. Those early synthetic fibers still originated in a natural source—cellulose from wood pulp—but soon enough in the 1930s, 40s, and 50s, a stream of synthetic fibers came on the scene that owed their origins to chemical plants instead of plants that could be grown in a field.

Now at the beginning of the 21st century, the trend in fiber research has come full circle. While the popularity of completely synthetic fibers remains high, in many cases attention is once again being focused on synthetic fibers that come from natural sources.

STARTING THE (COTTON) BALL ROLLING

Once the king of fibers, cotton textile fiber usage began to decline in the 1960s and 70s with the growth of applications for synthetic fibers and their increasing popularity. Cotton producers decided to fight back. Cotton Incorporated's famous marketing campaign is credited for bringing the public's attention and loyalty "back to nature."

"Cotton is the original high-tech fiber," says the company's Michelle Wallace. The fiber's material properties, such as moisture management, comfortable hand, and wet tensile strength contribute to its appeal. The development of various finishes has given cotton fabrics additional favorable properties, such as abrasion resistance, stain repellency, and wrinkle resistance. In addition, according to Wallace, genetic research has gone into improving the quality of the fiber itself—qualities such as increased length, and improved strength of the fiber over the last 30 years. "In the marketplace, it is important to have a differentiated product," notes Cotton Incorporated's Ira Livingston. "We are continually looking for ways to introduce cotton that surprises the consumer. One of those ways is our research into biogenetics, to enhance..."
cotton and to keep it a brand new 6000 year old fiber."

Cotton's resurgence has awakened researchers to the appeal of natural fiber sources. As well as being a renewable resource and biodegradable, cotton fibers also have material properties that are appealing. And Cotton Incorporated's marketing has ensured that the marketplace is receptive to textiles made from natural fiber sources. "We brought the consumer back to a 'natural state of mind' with over 30 years of communication," notes Livingston. "This has opened up opportunities for other natural-based fibers."

BIOPROSPECTING

Natural fibers are either plant (cellulose) or animal (protein) based. According to Anil Netravali of Cornell University, "There are a lot of plants we haven't looked at yet," for textile fibers. His group is researching the manufacture of composites using fibers from various plant sources, such as flax, ramie, pineapple, jute, banana, bamboo, sisal, hemp, and kenaf.

Other groups are promoting soy fiber, made from the waste products of the soybean industry. "Soy fiber is a rediscovered product that has many uses," says Barb Keeling of Keeling's Krafts, who uses soy fiber in her doll making business. She notes that the fiber has been around a long time, and is only now seeing a resurgence of interest. "Henry Ford talked of soy fiber in the 1940s. He even had a suit and tie made from woven soy fibers."

Jonelle Raffino of South West Trading Co., who markets soy yarns under the trade name of Soy Silk, feels that the marketplace will be very receptive to this fiber. "Consumers are demanding new ideas and smart ideas. Soy fiber satisfies the consumer on a lot of levels—it is fabulously soft, reasonably priced, and appeals to the awareness of environmental issues."

Cargill Dow went back to basics when they developed polylactic acid fiber (PLA) that they market as Ingeo. "PLA was the first generic fiber registered by the U.S. Federal Trade Commission in almost 50 years," notes Cargill Dow's Joe Raffo. PLA fibers are made using lactic acid as the basis for the polymer. The lactic acid comes from fermenting natural sugars or starches. Ingeo is manufactured using feed corn, but Cargill Dow is developing a way to use the corn stalks—a part of the plant usually considered a waste product. Other researchers are looking into using rice starch to manufacture PLA. Sustainable PLA fiber manufacturing from waste plant material is an exciting idea for many. According to Nexia Biotech's Ali Alwattani, "The potential to make fiber from waste biomass ... could create big, renewable feed stocks of high value fiber that does not drain the environment and can come from multiple rather than single supply sources."

As well as the plant world, the animal kingdom contains many more protein sources for fibers that have yet to be exploited. One of these is chitin, from the waste products of the shellfish industry. According to Sam Hudson of North Carolina State University, "Chitin is considered the second most plentiful renewable resource on earth, after cellulose." The shellfish waste is treated to extract the chitin, like wood chips are treated to extract cellulose fibers in rayon production. "We have known about chitin for many years," explains Hudson. "It was first chemically identified in the early 1800s, but in the last 10-15 years, interest has been picking up."

Another "hot" area of fiber research is spider silk. "Spiders have evolved a toolkit of as many as seven types of silks that they use to construct webs. With over 37,000 described species of spiders on the planet and all them producing silk, this makes for a wealth of opportunities for fiber researchers to bioprospect," says the University of California—Riverside's Todd Blackledge.

INTRIGUING POSSIBILITIES

For researchers, the allure of these new fiber sources lies not just in their availability or sustainability, but in their intriguing material properties and possible applications. "Chitosan (the fiber form of chitin) is not as strong a fiber as cotton or nylon. It is also sensitive to..."
acidity—it can dissolve in an acid solution (vinegar can turn it into a gel). It is also too expensive to manufacture to compete with rayon as a commodity fiber. However, it is an excellent special purpose fiber for medical applications,” says Hudson. Among its attractive fiber properties, chitosan is non-allergenic, has beneficial bioactivity, and is naturally antimicrobial. “The surface of the fiber resists bacterial colonization,” says Hudson. “It is being promoted for odor control because of its antimicrobial properties.” However, chitosan’s most useful property is that it’s haemostatic (efficient at stopping bleeding). One current application uses chitosan in a haemostatic bandage to stop arterial bleeding. Not only hospitals, but military organizations have keen interest in this application.

Marketability
According to Raffo, PLA’s material properties enhance its marketability. “Different aspects of the fiber make it useful in different markets.” The fiber’s natural fire retardance makes it useful for drapery, office panel systems, wallcovering, and upholstery. Its ability to wick moisture like cotton but dry quickly like polyester make it appealing for apparel. Low odor retention and UV transparency (sunlight doesn’t degrade it) make it attractive for apparel, carpeting, home furnishings, and drapery. “The fiber’s sustainability becomes a ‘throw-in,’” says Raffo. “People like to be environmentally conscious as long as it doesn’t affect price. Performance is the most important thing.”

PERFORMANCE
Performance is the attractive feature for spider silk fibers. Researchers are impressed with its material properties. According to the University of Wyoming’s Randy Lewis, “Spider silk’s tensile strength is as high as Kevlar, with elasticity as high as nylon. No manmade fiber has those combined properties.”

“Spider silk is a hot field right now because spiders have evolved a toolkit of as many as seven types of silks that they use to construct webs. Some of the types of silks in this ‘toolkit’ are relatively stiff fibers with high tensile strength, approaching that of our best manmade fibers. Others are highly elastic and stretch almost as much as rubber. Many of these silks absorb kinetic energy better than almost any known natural or artificial fibers, which is what really distinguishes spider silk,” says Blackledge.

Both medical and military applications suggest themselves with these material properties. “Spider silk has been suggested for military use as bullet resistant armor because it can absorb immense amounts of kinetic energy without breaking. For that reason, it has also been considered in applications such as high performance ropes (like the cables that stop planes when they land on aircraft carriers),” says Blackledge. “Some spider silks also supercontract (that is, the fibers get shorter and tighter when wet). This is unique, and means that spider silk could be used to make high performance sports clothing that fits better as athletes sweat more, or emergency bandages that contract as victims bleed more, like an automatic tourniquet.”

Potential
According to Lewis, medical applications could include artificial ligaments and tendons. Michael Ellison at Clemson University suggests that it might serve well as scaffolding for cell growth for tissue cultures, or for vascular grafts. Other applications are also possible—such as automobile airbags (spider silk absorbs energy), or apparel (spider silk takes up dye well). “The cost of production would be the only factor limiting the possibilities,” says Lewis.

The possibilities become even more limitless when you consider the goal of
many spider silk researchers. “We are studying spider silk and other naturally occurring materials in an attempt to identify proteins that make up the polymer,” explains Ellison. “Synthetic polymers have a much simpler structure. Natural protein polymers are much more complex, giving us much more to play with.” Spiders spin different kinds of silk, each with different material properties. “All of these silks are different from one another in their material properties, but ultimately evolved from the same ancestral silk,” notes Blackledge. “This means that if we understand how DNA, which provides the genetic blueprint for silk proteins, contributes to this diverse array of unique properties, then we can bioengineer spider silk fibers to have the exact material properties needed for a particular application by manipulating silk genes.”

Currently, researchers are inserting the bioengineered spider silk genes into an “expression medium”—basically, a delivery system that can manufacture the proteins they want in a solution. Ellison uses yeast as his expression medium. Lewis notes, “We can get bacteria and plants to make the proteins as well. Our group is currently looking at alfalfa, because alfalfa normally produces a high protein content.” Nexia Biotech has developed a biopolymer raw material with the same biochemical composition as the polymer in spiders and is now developing a process to convert this biopolymer into fiber. Nexia’s expression system for their synthetic spider silk proteins is genetically modified goats. The protein is isolated from the goats’ milk.

**BY DESIGN**

**Material Properties**

The opportunities and implications presented by the bioengineering of spider silk proteins are far-reaching. Bioengineered natural materials are different from traditional natural fiber sources, because bioengineering allows some control of the material properties of the fiber according to the demands of the application. Bioengineering gives you control of the physical form of the fiber. Notes Alwattari. “You can make an artificial silk fiber in a controlled predictable diameter—potentially up to a larger size scale monofilament diameter than is presently available from the silk farm.” Because the biosynthetic protein polymers are purpose designed, the manufacturer can also design how quickly the product should biodegrade.

**Green Manufacturing**

As well as studying the protein structure of spider silk in an effort to design their own protein fibers, researchers are studying how the spider itself manufactures its silk. “Spiders produce silk at ambient temperatures without...”
the use of caustic chemical or acids,” says Blackledge. Researchers would like to discover ways to mimic that production method. According to Ellison, “Synthetic polymers use a ‘brute force’ method of creating fibers. Quite a bit of energy is put in, and a lot of waste products result. We’re studying how the spider manages to turn the protein solution in its silk duct into a fiber by the time it exits its spinneret. The spider removes moisture from the protein in a controlled way, so that when the silk exits the spinneret, it is totally formed. The way the spider produces fiber is much more sustainable than the way we do it. We’re studying these natural production methods to make our own production methods much more sustainable. We’d like to eliminate problems such as effluents and excessive energy consumption.”

THE FUTURE

Discovery

According to Lewis, “The role of polymer chemistry in discovering new fibers is slowing down. Current developments indicate they are not discovering new types of fiber materials at nearly the rate they had been. Biogeneticists can do things a polymer chemist never dreamed of.” Ellison notes that researchers have only begun to study in detail the material properties of spider silk. Other material properties worth exploring include the silk’s sensitivity to humidity changes and to barometric pressure, as well as its ability to supercontract when exposed to liquid. “Spider silk also has piezoelectric properties. We might be able to use those properties to design a sensor or an actuator out of spider silk proteins.”

Ellison points out that there are other natural fiber proteins that researchers are looking into as well. They are revisiting the traditional source of silk, the silk worm, with an eye towards investigating its genetics. They are also looking at mussels. “They have a thread that they use as an attachment mechanism that has an interesting structure,” says Ellison. “The same thread’s structural and mechanical properties are different where the thread attaches to the organism (the thread is flexible) and where the thread attaches to an anchor point such as a rock (where the thread is stiff and inflexible).”

Competition

Despite interesting material properties of the new “natural” synthetics, they will certainly face competition from their traditional synthetic brethren. “ Petrochemical-based synthetic fibers are like cotton are commodities. With a natural synthetic like PLA, the price will go down as the demand increases. Manufacturers will be able to see a good profit margin.”

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PRICE

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Price and Performance

Alwattari says that renewability will be a major issue for new fibers. However, performance is vital as well. “New benefits have to be big, not incremental. As fibers become value added materials beyond textiles (e.g., composites, drug-delivery systems, etc.), there is an opportunity to shift away from scale/cost driven innovation to performance driven innovation—solving previously unsolved problems for customers.”

For the future of fibers, Alwattari sees “specially formulated and processed materials that are engineered to respond in dynamic and in-use situations such as the delivery of active materials, detection, and controlled mechanical response and resistance.”

He also notes that cost will be a major issue. “It is a manifestation of simple market reality that materials with improved performance to cost ratio, such as cheaper or lighter weight, will displace incumbents that are subpar in performance to cost for their particular application.”

Raffo sees the new fibers as a value-added proposition. “The price of traditional synthetic fibers is linked to the price of petroleum. Traditional natural fibers like cotton are commodities. With a natural synthetic like PLA, the price will go down as the demand increases. Manufacturers will be able to see a good profit margin.”

Opportunity

The opportunities represented to the fiber industry by the movement back to nature are great. The new natural fibers promise new and intriguing material properties that may take them into applications beyond the arena of “just textiles” into performance materials. They promise an opportunity to add value to products in the textile chain. And they definitely promise the benefit of sustainability and environmental awareness. “I see an opportunity for the textile industry to reinvent itself with huge success,” says Raffo. “The consumer wants soft, luxurious fibers that are environmentally aware. We can provide it. We, as an industry, have the means.”