Clean and Innovative Textiles Strategy for Circular Economy

MODULE 3
Sustainable Fibre/Material Resourcing

Unit 3.1
Natural Fibres

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In this lecture you will gain knowledge about natural fibers, their distribution, similarities and differences, and the possibilities of using natural fibers.

What is Natural Fibre? Natural fibre, any hairlike raw material directly obtainable from an animal, vegetable, or mineral source and convertible into nonwoven fabrics such as felt or, after spinning into yarns, into woven cloth. Natural fibers include those produced by plants, animals, and geological processes. They are biodegradable over time. They can be classified according to their origin [1].

Vegetable (Cellulose) Fibre. Fibers from plant or vegetable sources are more properly referred to as cellulose-based and can be further classified by plant source. They may be separated from the plant stalk, stem, leaf, or seed [1,2].
Fibers from plant or vegetable sources are more properly referred to as cellulose-based and can be further classified by plant source. They may be separated from the plant stalk, stem, leaf, or seed. Fibers from animal sources are more properly known as protein-based fibers. They are harvested from an animal or removed from a cocoon or web. Mineral fibers are those that are mined from the earth. Except for silk, all natural cellulose- and protein-based fibers are obtained in short lengths and are called staple fibers. Silk is a continuous filament fiber [3].
Cellulose-based fibers consist of bast, leaf, and seed-hair fibers. Bast fibers come from the stem of the plant and include flax, hemp, jute, and ramie. Leaf fibers are stripped from the leaves of the plant and include manila and sisal. Seed-hair fibers are collected from seeds or seed cases and include cotton and kapok [1,2].

Seed hair: cotton, kapok. There are four different types of cotton, each with its own characteristics:
Pima cotton. Considered the finest type of cotton in the world, pima cotton's fibers are extra soft and extra long. Pima cotton fabric is very highly-sought after, as it is resistant to fading, tearing, and wrinkling. **Egyptian cotton.** Egyption cotton is very similar to pima cotton. The two are even in the same scientific class: gossypium barbadense. It has the same resistant qualities, but it is grown in the Nile River Valley in Egypt. **Upland cotton**. Upland cotton has very short fibers and makes up about 90% of the world's total cotton production. **„Organic" cotton.** Eco cotton is any type of cotton that is grown without chemicals and from plants that are not genetically engineered [1,2].
Characteristics of Cotton fibre. Cotton has a number of distinguishing characteristics that make it such a popular fiber in the textile industry. Softness. The cotton plant is soft and fluffy and results in a fabric often retains that soft feel. Durability. The cotton plant's cellular structure is strong, creating a tough and wear-and-tear resistant fabric. Absorbency. Cotton fabric is very absorbent fabric because there is a lot of space between the cotton fibers. Holds dye well. Due to its absorbent nature, cotton takes dye very easily and can be made into a wide variety of colors. Breathability. The fiber structure of cotton makes it more breathable than synthetic fibers. No static cling. Cotton does not conduct electricity, therefore static is not an issue with cotton. Kapok is from the seed pods of the Java kapok tree (Ceiba pentandra). The seed pod is similar to the cotton boll; however, the dried fibers are easily shaken off the seed. Kapok fibre cannot be spun into yarns because they are very weak. Their density is only 0.35 g/cm^3], due to the large air-filled lumen. The fibres are water repellent, fine, soft, and lustrous. A buoyant fiber, kapok is used primarily in life jackets, as special stuffing for pillows, and in some mattresses [1,2,3].

Bast fibres: flax, hemp, jute, ramie, nettle. Bast fibers are a great sustainable alternative to the synthetic materials we commonly use today. Here are three bast varieties that can make great eco-friendly towels and textiles. The bast fibers are gained from the vegetative part of the plant: stems of flax, linen or hemp plants. Consequently, the quality parameters for these fibers are developed before the harvest of the fruits [1,2]. **Flax (Linen)** is valued for its strength, lustre, durability, and moisture absorbency. It is resistant to attack by microorganisms, and its smooth surface repels dirt. It is stronger than cotton, dries more quickly, and is more slowly affected by exposure to sunlight. It can be bleached to a pure white but dyeing is somewhat difficult because the fibres are not readily penetrated. Although linen increases in strength when wet, the excessive use of alkalies in laundering can weaken

the fibres. Low elasticity, imparting hard, smooth texture, also makes linen subject to wrinkling, which can be reduced by chemical treatment. Because linen absorbs and releases moisture quickly and is a good conductor of heat, linen garments have a cooling effect on the wearer. Hemp fibre comes from the stem of the plant, which makes it a bast fibre. The stems consist of a central woody core (called the shives or straw) surrounded by the bundles of fibres (the bast) which are covered by an outer skin. Hemp processing is very similar to flax processing. First the stems need to be rented, by soaking them in water for a few days or dew retting on the grass [1,2].

As the hemp plant is very tall, up to 5 metres, the fibre bundles are long, from 120 to 210 cm long or even longer. Hemp fabrics are very similar to linen and both have the same interesting texture. Like linen, hemp wrinkles easily adding character to the garment and giving it a carefree look. Hemp fabric is not stretchy and it can feel stiff at first, so it is often blended with cotton to make it softer. However, hemp does become softer with washing and use. Of course, hemp is breathable and biodegradable like all other natural fibres. Its main properties are: Sustainable and environmentally friendly fibre; One of the strongest and most durable natural textile fibres; Absorbs moisture, prevents bacteria formation; Blocks ultraviolet rays; Superior durability; Easily recyclable [4,5]. **Jute** fibres are very long (1 to 4 metres), silky, lustrous and golden brown in colour. In contrast to most textile fibres which consist mainly of cellulose, jute fibres are part cellulose, part lignin. Cellulose is a major component of plant fibres while lignin is a major component of wood fibre; jute is therefore partly a textile fibre and partly wood. Jute fibre has strength, low cost, durability and versatility. Jute is used where low cost is more important than durability, for example in coffee sacks and cotton bale covers. You are probably familiar with jute as twine used to tie garden plants, and as hessian fabric (or burlap in the US). Jute is used in shopping bags, carpets and rugs, backing for linoleum floor covering, chair coverings and environmentally friendly coffins. Why Jute is an Environmentally Friendly Fibre? Jute has a low carbon footprint, it is biodegradable, feeds the soil and all parts of the plant can be used. Jute plants help to clean the air; during growth they assimilate three times more CO_2 than the average tree, converting the CO_2 into oxygen [3,6].

Ramie is a bast fiber from the stalk of the ramie plant (Boehmeria nivea), also known as “China grass.” The plant is a perennial shrub that can be cut several times a year once mature. The cut plant’s stalks are peeled or retted to remove the outer woody covering, revealing the fine fibers underneath. Degumming removes pectins and waxes, followed by bleaching, neutralizing, washing, and drying. The fiber is similar to flax, but more brittle. Ramie can be spun alone or with other fibers, especially cotton. You can compare the properties of plant fiber [7,8]. Nettle fibre. Nettle fibres have been labelled the material of the future, being ecologically friendly, sustainable. The fibres come from the nettle plant stem. The stem is cut and the bark removed allowing the fibre to be extracted with all the thorn-like stinging hairs removed. These fibres are then carded and spun producing a very strong cord useful for string, rope or fishing nets. For yarns, these fibres are usually blended with cotton or wool [9,10].

Leaf and other cellulose fibres: sisal, manila, peat. Leaf fibers or hard fibers are a type of plant fibre mainly used for cordage (producing rope). They are the toughest of the plant fibres which is most likely due to their increased lignin content when compared to the other groups of plant fibres. They are typically characterized as being very tough and rigid lending them towards being used in rope production over clothing or paper like other plant fibre [1,2]. **Sisal** is from the leaves of plant Agave sisalana. The leaves are cut when the plant is about four years old, and the fibers are separated from the fleshy part of the leaf. Sisal has industrial uses, most commonly as a rug or carpet backing. Sisal fibers have some eco-friendly advantages like low density, cheaper availability, good specific strength and modulus, which make them suitable for use as reinforcement in composites, and for applications in manufacturing of roofing tiles, carpets, fancy items like purses, wall hangings, automotive parts, and also in some construction materials [1,2]. **Manila** is from the leaf stalks of the abacá plant (Musa textilis). The fibers are separated from the fleshy part of the leaf stalk. Manila is generally used in rope and cordage [1,11]. **Coir fibre.** Seed fibre from coconut palm. Coir fibre have a very high abrasion resistance, are very durable and have good elasticity. They do not soil easily, are good insulators and

are resistant to rotting. They are often used in the raw form. Coir is used primarily for padding materials in the automobile industry, but also for stair-carpets, doormats, floor coverings, stuffed furniture backings, and brushes. Peat fibre is an ecologically sustainable Finnish alternative with a low carbon footprint, and it allows energy-efficient production. Peat fibre is naturally mould-resistant, requiring no added chemicals to prevent mould fungus growth. When it dries, it becomes water-repellent. Peat fibre is also a suitable ingredient for different construction, decoration and acoustic boards as well as nonwoven fibre fabrics, compression molding products and composites [1,2,11].

Protein fibres. Animal fibres are the second most widely used natural fibers after vegetable fibres. They are generally comprised of proteins. Examples of this fiber include wool fiber obtained from sheep, goats, lamas, rabbits. Similarly, silk, feathers, and hair are obtained from various sources. Wool and silk fibers differ in many perspectives [1,2,11]. Wool fiber is formed by keratin protein and growth from an outer skin layer like from a sheep or goat. Silk fiber is a protein fiber from silk glands of an insect [12]. Keratin fibres, such as wool, alpaca and human hair, have complex structures and morphologies. The fibre surface is covered with scales, which are collectively referred to as cuticles. This slide show Types of wool. The term "wool" also may be used to identify fibers from other fleece animals, such as the Angora goat, Cashmere goat, camel, alpaca, llama [13]. The properties of wool fibers differ from each other [14]. Alpaca fiber is a lighter and warmer fiber compared to sheep fiber, and is almost white in color, whereas angora fiber obtained from the Angora rabbit is a thin and soft fiber. Cashmere fiber obtained from the cashmere goat is a luxurious soft wool fiber. Although the aforesaid said fibers possess various properties, sheep fiber is the most widely used fiber due its wider availability and cheaper price. Sheep-wool fiber can be sheared from the living animal or pulled from the hide after slaughtering. Sheared or clipped wool is superior to pulled wool [1,2]. Sheep normally are sheared only once a year. Scanning electron microscopy (SEM) images of wool show fibre cross-section is round [15]. The scales on the fibre surfaces are capable of hooking onto one another to cause felting, under the influence of water, heat, and mechanical action. Appearance is overlapping scales, like roof tiles. **Merino wool.** Merino wool comes from the merino breed of sheep which have their origins in Spain, though much of today's merino wool is exported from Australia. Merino wool is known for its fine fibers which offer a supremely soft hand and make it a great material for garments like base layers that have direct contact with the wearer's skin. Merino wool also has a lower yield compared to other wools because of the scouring process which is required in order to remove the fatty greases inherent to the material. Scouring washes, the wool in chemicals to remove the natural lanolin layer, but the process yields only about half of the initial wool. This laborious process makes merino wool pricier than other wools [1,2]. **Alpaca** is the long, fine hair fiber from the alpaca, which is a relative of the camel native to South America. It is shorn from the animal once every two years. The soft, fine undercoat is used in textiles. Alpacas are native to South America and produce hairs that are hollow. This unique property not only makes alpaca lightweight but also adds greater insulation. It is both lighter and warmer than sheep's wool. Compared to cashmere, alpaca is similarly soft, but notably stronger. Alpaca hair is naturally hypoallergenic as well, making it ideal for those with sensitive skin. Alpaca wool Scanning electron microscopy (SEM) images show the same fibre surface as sheep-wool [16]. **Cashmere** is the soft hair fiber from the cashmere (kashmir) goat. The fiber is harvested by combing the animal. A single goat produces only about 114 grams of fiber a year. Cashmere is considered a luxury fiber. Llama hair fibers are shorn from the animal once a year. They are similar to alpaca fibers, but weaker. Cashmere is shorn from the undercoat of cashmere (Kashmir) goats when they enter the molting season. Because cashmere is shorn from the undercoat, the yield per goat is small, requiring two cashmere goats to produce a single sweater. The wool produced by these special goats results in an extremely fine fiber with about the same thickness of ultrafine merino and a considerable jump in price [1,2]. Cashmere wool Scanning electron microscopy (SEM) images show the scales are capable of hooking onto one another [15]. **Mohair** is the long, straight, fine hair fiber from the Angora goat. The fiber is usually sheared from the animal twice a year. Mohair comes from the Angora goat and is distinct from other wools for several reasons. The guard hairs from the topcoat of the goat are often included with the undercoat in the shearing process. Though the fibers are thicker, the mild climate in which Angora goats are grown means it's not as coarse as other wools —

its longer length gives the fiber its smoothness and results in a uniquely fuzzy fabric [1,2]. Most **camel** hair comes from Bactrian camels, which are bred in frigid regions like Mongolia, China and Russia, and is collected when the camel molts in spring. Camel hair is hollow like mohair and is finer and longer than sheep's wool [1,2]. The result is a fiber that's lighter and more lustrous than sheep's wool and about as soft as cashmere. Though camel hair takes dye well, it is often kept in its natural color, a light, golden brown, and is used synonymously to refer to the color itself. Camel wool Scanning electron microscopy (SEM) images show the same fibre surface as sheep-wool. Llama fibre is one of the finest natural fibres in the world [15]. Llama fibre is almost completely lanolin free and is actually a hollow hair as compared to "wool". It is lightweight and very strong with amazing thermal properties. One of the best qualities (aside from it's fineness) of this fibre is the fact that it is hypo-allergenic making it easy to wear for just about everyone. It is lovely when blended with sheep's wool, cashmere or silk [1,2]. SEM scanning demonstrates that the cuticular cell length, height, and scale edge angle of llama fiber is measurably different from wool [18].

Angora is the long, fine hair fiber from the Angora rabbit. It is not to be confused with the hair fiber of the Angora goat, the source of mohair. Angora rabbits are raised domestically. The fur is combed and clipped from the rabbit every three months Angora fibers, like alpaca, are hollow and smooth giving it unrivaled warmth and loft. The fibers are extremely soft, but also very delicate [1,2,11]. For this reason, angora is often mixed with other fibers to increase its durability. The extreme fineness of angora makes it prone to matting and felting — another reason why it's mixed with other fibers — but also requires angora breeders to comb the rabbits every day. This intensive process and low yield add up to a hefty price. Colour-enhanced Scanning Electron Micrograph (SEM) of Angora hair, or fiber, the downy coat produced by the Angora rabbit. It is different from mohair, which is produced by the Angora goat [15]. Angora fiber is also distinct from cashmere, which comes from the cashmere goat. Angora is known for its softness, thin fibers, silky texture, and what knitters refer to as a halo (fluffiness). It is warmer and lighter than sheep's wool.

Wool classification and their properties [19]. The Horse hair shaft is made up of overlapping scales of dead cells containing the protein keratin [15]. The outside of the Human hair, the cuticle, is covered in overlapping scales that protect the hair's central cortex, which is made up of the fibrous protein keratin [15]. Wool is 100% natural keratin fibres and 100% biodegradable. When a wool fibre is disposed of, it will naturally decompose in soil in a matter of years, slowly releasing valuable nutrients back into the earth. Wool is 100% renewable. Warm and cool. In contrast to synthetics, wool is an active fibre that reacts to changes in body temperature. So it helps you stay warm when the weather is cold, and cool when the weather is hot. Wrinkle resistant. At microscopic level, each wool fibre is like a coiled spring that returns to its natural shape after being bent. Fashion designers and activewear brands can choose from a range of innovative treatments and manufacturing techniques to create unique textures and finishes on wool garments. Naturally breathable. Wool fibres can absorb large quantities of moisture vapour then move it away to evaporate into the air [20].

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Properties of wool: Odour resistant. In contrast to synthetics, wool can absorb moisture vapour which means less sweat on your body. Wool even absorbs the odour molecules from sweat, which are only released upon washing. Soft on skin. Wool fibres are extremely fine, enabling them to bend far more

than traditional, coarser wool fibres. This makes wool feel soft and luxuriously gentle next to body skin. Naturally elastic. Natural elasticity helps wool garments stretch with you, yet return to their original shape [20]. Fire resistant. Wool's inherent chemical structure makes wool naturally flame resistant. It is a highly trusted natural fibre in public areas such as hotels, aircraft, hospitals and theatres. Whilst cotton catches alight at 255°C, the temperature must reach 570-600°C before wool will ignite; while polyester melts at 252-292°C and nylon succumbs at an even lower 160-260°C, wool never melts so it can't stick to the skin like many common synthetics. UV resistant. Wool clothing provides good protection from the sun, compared with the protection from other fibres [20].

Fibroin fibres: natural silk, spider silk. Natural spider silk is a natural protein biomaterial secreted by spiders through their silk glands. It belongs to a type of bioelastic fibre. It is one of the best materials produced in nature. **Silk** is a natural protein secreted by the larvae of several moth species. The larvae use the filaments to construct a cocoon, from which the silk is extracted. Twin filaments of the protein fibroin are secreted and bound together in a single strand with the protein gum sericin. During processing, the sericin is removed, leaving the fibroin protein. Cultivated or cultured silk is produced in very controlled conditions of environment and diet. Tussah or wild silk is harvested from natural sources. Silk is another important natural protein fiber obtained from various sources which can be woven into textiles [21, 22]. **Spider silk.** Another type of the silk fiber was produced by a spider. Spider silk is incredibly tough and is stronger by weight than steel. Quantitatively, spider silk is five times stronger than steel of the same diameter. Spider silk is also very elastic and capture silk (sticky silk for catching prey) remains unbroken after being stretched 2-4 times its original length. Spider silk is tougher, more elastic and more waterproof than silkworm silk so it could have a much wider range of applications. It is simple to see why spider silk is of such interest to materials chemists since new ultra-strong fibres based on the silk could be developed [23].

Eco Friendly Fibers – Natural fibers. Natural fibre, such as cotton fibre is free of impurities but only when no harmful pesticides or insecticides are used in its cultivation. If so, then it is environmentally friendly. However, even if they are produced sans any of these harmful substances, they can become 'polluted' when processed for making yarns and fabrics because of all the textile chemicals used on them. Same is the case with animal fibre like wool which can get contaminated due to pesticides used in sheep dips or a variety of drugs used for treating animal diseases. However, when the plant fibre, cotton for example once again, is cultivated without any harmful pesticides and with the help of composted manures and cover crops then only can it be said 'organic cotton' which is 100% eco-friendly fibre [24,25].

The literature provided will give you the opportunity to delve deeper into natural fibers.

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