MATERIAL INNOVATION INITIATIVE

WHITE SPACE #1

SUB-CATEGORIES WITH LIMITED INNOVATION 2024

Image Credit: Monark / shutterstock
Milkweed is used to make next-gen down by companies like Monark.

MATERIAL
INNOVATION
INITIATIVE

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Image credit: Metsä Spring

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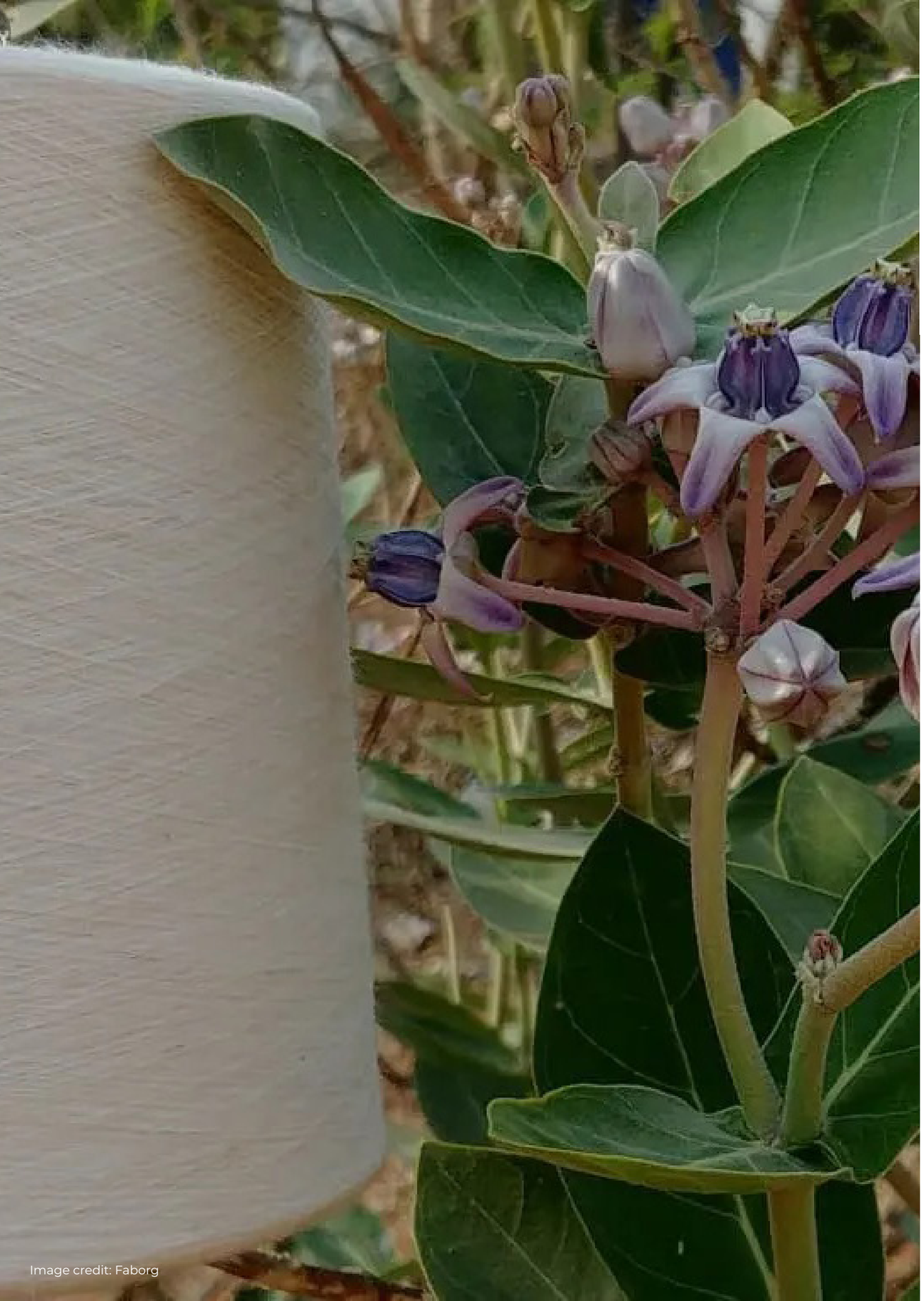


Image credit: Faborg

INTRODUCTION TO MII'S WHITE SPACES

In Q4 of 2021, the Material Innovation Initiative (MII), in collaboration with The Mills Fabrica, published a White Space Analysis Report outlining the seven critical white spaces within the next-gen materials industry. In this new white space mapping process we seek to look at the material landscape up and down the value chain with a new lens. We want to identify unmet and unarticulated needs. These are not only missed opportunities, but a lot of times also barriers to the growth and adoption of next-gen materials. We need to direct interests, attention, and resources to fill these gaps for the benefit of accelerating the entire next-gen materials industry. Whether you are a material startup looking for high growth opportunities, a scientist developing a new technology or material, a brand looking for the future trends and needs of sustainable products, or an investor thinking of strategically diversifying into next-gen materials, we are certain this report will inspire your next move.

For this updated series, we are publishing a report for each of the seven white spaces. This will give us more opportunity to focus attention and resources on each individual white space. It also allows you, our audience, smaller bite-sized reports which are easier to digest and lets you focus your attention on your areas of greatest interest and potential impact. In this report, you will find White Space 1: Sub-categories with limited innovation. Ensure you sign up for our newsletter to be notified when we publish the other White Space Reports.

About MII

Our mission is to accelerate the availability of high-quality, high-performance, animal-free, and environmentally preferred materials ("next-gen materials") with a focus on replacing silk, wool, down, fur, and leather and their synthetic alternatives. We are powered by philanthropy - if you want to support analysis like this please consider donating! Learn more at www.materialinnovation.org/

New to MII's analyses?

Start with our series of State of the Industry Reports for the annual deep-dive on the next-gen industry including the key players, investments, trends, and news within the industry.

WHAT ARE WHITE SPACES?

We use the term white space to refer not only to areas without current competition, but also to new technology and gaps in existing markets. We identify seven areas with significant opportunities for innovation in the next-gen materials industry, broadly defined. Our goal is to direct interests, attention, and resources to innovate for the benefit of accelerating the entire next-gen materials industry.

These seven hotspots we identified in our 2021 analysis were the key, overarching areas in our 2021 analysis were the key, overarching areas of technical challenge and opportunity within this nascent industry. Nearly 3 years later, despite burgeoning progress, these white spaces remain active needs in the next-gen industry. In this new series, we reframe these seven white spaces with updates on notable progress, alternative perspectives, explainers, and external resources to help understand these white spaces further. Feel free to grab the original report as your companion, and take a dive into the white space.

WHITE SPACE 1:
Sub-Categories with Limited Innovation

The industry's early movers and shakers have focused on next-gen leather, but there is untapped potential in other animal material mimics like silk, wool, down, and fur.

WHITE SPACE 2:
Bio-Based Resins, Coatings, Binders, Dyes, and Finishes

How do we ensure that the whole formulation of a material or product is consciously designed so that all components, not just the fiber or substrate, are environmentally preferable?

WHITE SPACE 3:
Beyond Polyester

Synthetic fibers may be the textile industry's current problem child, but the right innovation with plant-based chemistries could make these adaptable materials work for us.

WHITE SPACE 4:
New Bio-Feedstocks

Focusing on smarter sourcing and manipulation of plants, algae, and fungi with the goal of creating cellulosic and natural fibers could unlock a new pool of next-gen innovations.

WHITE SPACE 5:
End of Life

What do we do with next-gen materials at the end-of-life? Circularity could be the solution, but we need to be thoughtful and have several plans of action.

WHITE SPACE 6:
Materials Science Done Right

It's less effective to think "what can I do with this stuff?" when developing a new product than to identify the necessary product attributes and design for need.

WHITE SPACE 7:
Biotechnology Scale-Up

We've seen lots of starting up, now we need to scale up. What are the unique issues that biotech materials innovations must conquer to get to market?

MATERIAL INNOVATION INITIATIVE

UNDERSTANDING INNOVATION

1) Materials are one solution of many. We should not expect next-gen innovators to single-handedly solve the vast challenges of disrupting the global textiles, chemicals, and additives markets.

2) Performance is key, even over sustainability. Performance and aesthetics are absolute requirements for next-gen products to be successful on the market, and meeting them may initially require sacrifices in certain areas of sustainability.

3) Innovation takes time. The research, development, and scale-up associated with novel, sustainable material feedstocks and chemistries that can be adopted by next-gen innovators takes time and investment.

4) "Perfect" does not exist. There is no such thing as a "perfectly sustainable" material or product.

At the Material Innovation Initiative, we believe in making progress with the goal of perfection. Perfection should not be the enemy of better. We trust that most innovators will rely on the best available options for sustainable formulation components, but completely phasing out less sustainable chemistries and additives is not always easy. MII will continue to identify and explain both opportunities and challenges so that the next-gen industry can iteratively move towards lower environmental impacts.

Image credit: Spiber Inc.

DEFINITIONS

"Next-gen materials" are animal-free and more sustainable than incumbent (animal-based) and current-gen (petrochemical-based) materials and replicate the high performance of the materials they are designed to replace. MII currently focuses on replacements for conventional animal-based leather, silk, down, fur, and wool. These next-gen replacement materials use a variety of biomimicry approaches to replicate the aesthetics and performance of their animal-based counterparts.

"Current-gen materials" are those used to substitute for animal-derived materials by winning on price. Synthetic leather made from petrochemicals, for example, sells at wholesale at one-third the price of the animal leather equivalent. We generalize these petroleum-based alternatives (e.g., polyurethane (PU), polyvinyl chloride (PVC), acrylic fiber) as "current-gen materials," but their current applications in the market are far beyond animal-based material replacements. More clothing is made from polyester and nylon, both plastics, than from cotton. Examples of "current-gen" alternatives include PU for leather, polyester for silk, or acrylic for wool.

"Disruptive textile technology" refers to material innovations that do not directly replace animal-based materials, but that may become promising feedstocks or resources for next-gen material innovation. Sustainable innovation in synthetics such as bio-based, biodegradable, or recycled polyester or polyurethane, and in sustainable renewable-sourced fibers such as cellulosics and natural fibers, could have broad impacts in the plastics and textiles industries as a whole, as well as in the next-gen materials space. MII hosts a disruptive textile technology database to provide next-gen material innovators an easy way to find potential collaborators or suppliers.

"Bio-based" refers to materials wholly or partly derived from biomass such as plants, trees or fungi (the biomass can have undergone physical, chemical or biological treatment).[1]

Image credit: Werewool

INTRODUCTION TO WHITE SPACE #1

Sub-categories with limited innovation

In the rapidly evolving landscape of next-generation materials, the quest for sustainable and ethical alternatives to traditional animal-based textiles is a pressing concern. Interest in next-gen materials is growing in all sectors. Despite global VC funding falling 42% and deal count falling 30% to reach a 6-year low in 2023, funding for next-gen materials companies increased.[1] The next-gen materials industry enjoyed a 10% rise in investment funding in 2023, showing significantly higher investments than the general market.[2]

Our comprehensive white space report delves into the burgeoning industry of next-gen silk, wool, down, and fur, highlighting the critical need for innovation and expansion in these sectors. Conversely, the number of next-gen leather start-ups is high, signaling a shift in focus towards other materials that are ripe for development.

STATE OF THE NEXT-GEN MATERIAL INDUSTRY AT A GLANCE (2023)

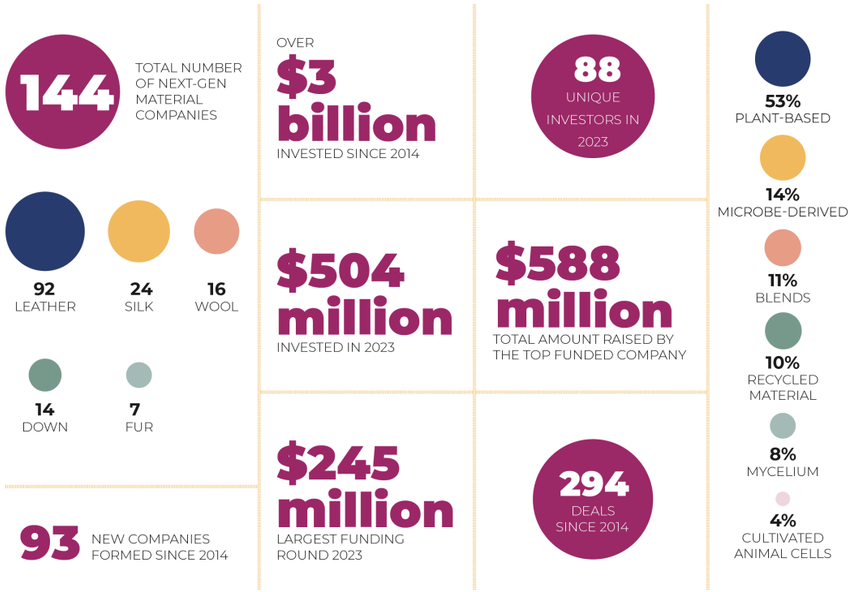


Fig. 1. State of the next-gen materials industry 2023

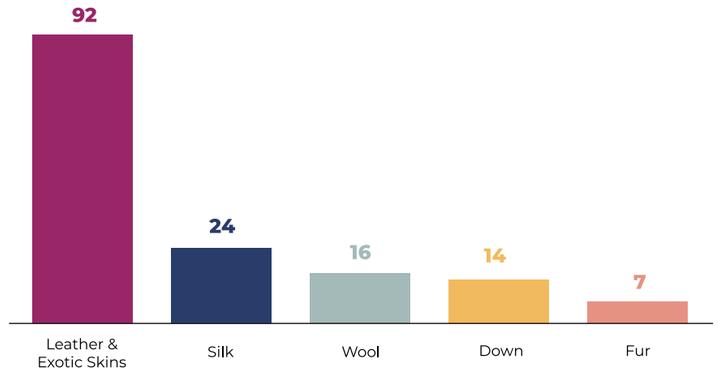


Fig. 2. Number of Companies by Next-Gen Material, 2023

Our report explores four pivotal aspects for each white space material:

Market Potential
What is the market size of the incumbent industries, and therefore, the market potential for their next-gen alternatives?

Uniqueness
What are some of the performance and aesthetic metrics any new material needs to meet in order to surpass the incumbent material?

Innovation Potential
How can these materials surpass their predecessors? Next-gen down, for example, could leverage advanced insulating properties and superior performance in wet conditions, addressing the limitations of natural down.

Creation Targets
What are some of the performance and aesthetic metrics any new material needs to meet in order to surpass the incumbent material?

This white space report serves as a clarion call for entrepreneurs and investors to channel their resources into the less saturated, yet equally vital, areas of next-gen wool, down, fur, and silk. By doing so, they will not only fill a significant gap in the market but also contribute to a more sustainable and ethical future.

MARKET POTENTIAL

Understanding the addressable market size of an existing product is a critical component in the analysis of the value of creating a new product. The addressable market size, often referred to as the Total Addressable Market (TAM), represents the entire revenue opportunity that exists within a market for a particular product or service.

Knowing the TAM helps businesses, entrepreneurs, and investors to:

1. **Gauge Market Potential:** It provides a quantifiable measure of the potential market demand, which is essential for assessing the viability and scalability of a new product.

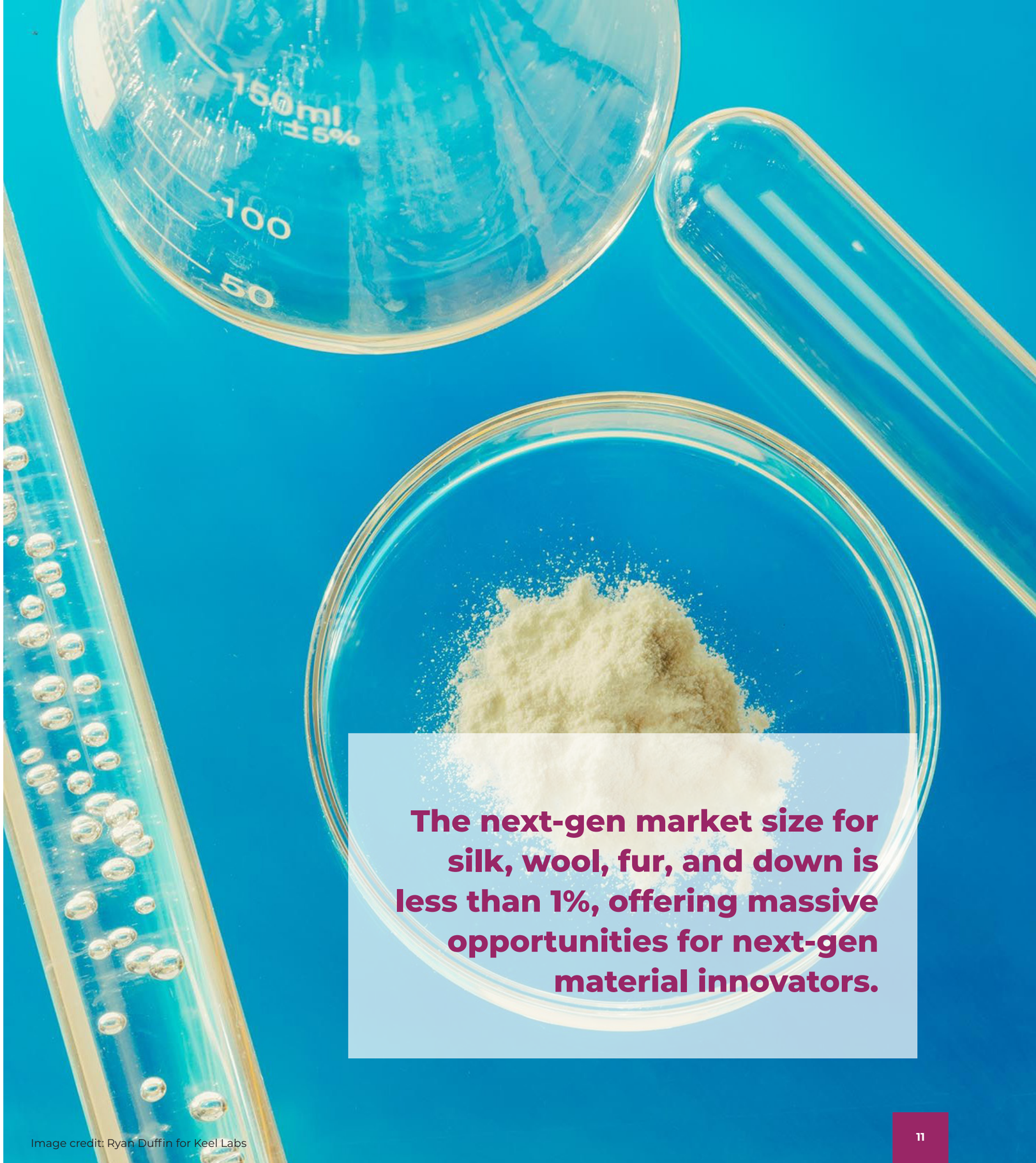
2. **Inform Strategy:** By understanding the size of the addressable market, companies can make informed decisions about product development, marketing strategies, and resource allocation.

3. **Prioritize Efforts:** It helps in prioritizing features, functionalities, and innovations that align with market demand, leading to more effective product development and a higher return on investment.

4. **Assess Competition:** Knowing the TAM allows businesses to understand the competitive landscape and identify how much of the market is already being served by existing products.

5. **Determine Product-Market Fit:** A larger addressable market can indicate a greater potential for growth and product-market fit, providing room for new products to enter the market and capture part of it.

The addressable market size is a key metric that supports the strategic decision-making process, enabling businesses to evaluate the potential success and financial feasibility of introducing a new product to the market. It's a foundational element that can significantly influence the direction and outcome of product development initiatives. Next, we discuss the TAM for silk, fur, wool, and down. Note that the next-gen market size for all of these materials is less than 1% offering massive opportunities for next-gen material innovators.



The next-gen market size for silk, wool, fur, and down is less than 1%, offering massive opportunities for next-gen material innovators.

Image credit: Ryan Duffin for Keel Labs

Silk/Polyester

Polyester was originally designed as a replacement for silk during a time when silk was in short supply, particularly during World War II. The goal was to create a fabric that could mimic silk's desirable qualities—its strength, lightweight nature, and ease of care—while being more readily available and less expensive to produce.[1] DuPont scientists developed polyester by synthesizing polymers derived from petroleum, creating a fabric that was durable and could be mass-produced, leading to its widespread adoption in the fashion industry.[2]

In addition, the technologies used to create next-gen silk are similar to those used for next-gen polyester. Both materials are often developed using the same advanced scientific techniques such as gene editing, fermentation of plant-based ingredients, and other biotechnological processes. Thus, entrepreneurs, investors, and innovators looking to recreate silk should also look to the polyester market, and vice versa, as part of the total addressable market.

The total addressable market size for next-gen silk is significant, with the global silk market being valued at around USD 20 billion in 2024 and projected to be worth USD 44.6 billion by 2034.[3] The market is expected to grow at a CAGR of 8.4% during these years.[4] Considering these figures, the silk market is experiencing significant expansion, driven by factors such as rising disposable incomes, fashion trends, and innovations in silk applications beyond traditional clothing.

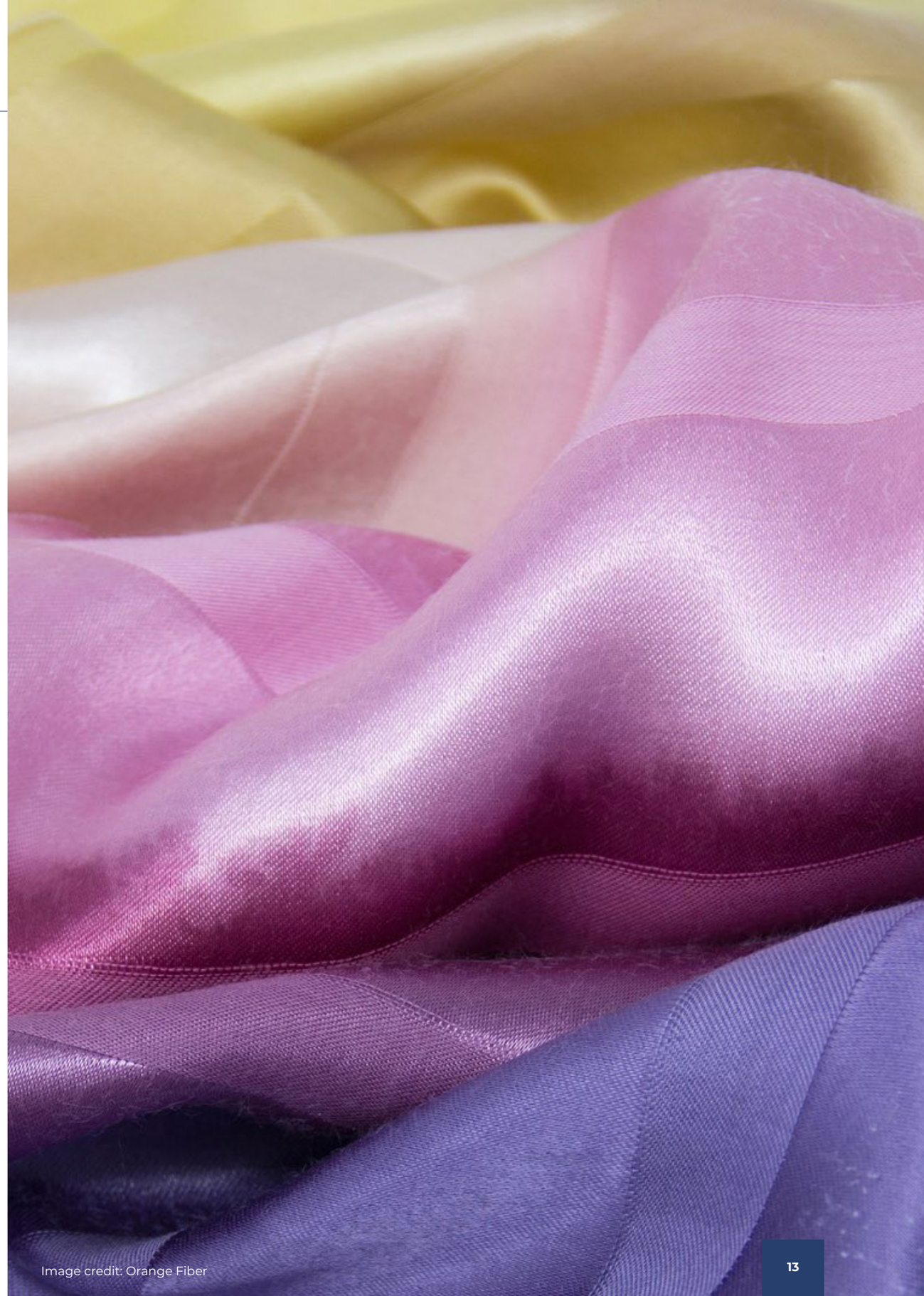


Image credit: Orange Fiber

Image credit: Alt Tex
Alt Tex's food waste fiber.

Global Silk Market Growth 2024–2034

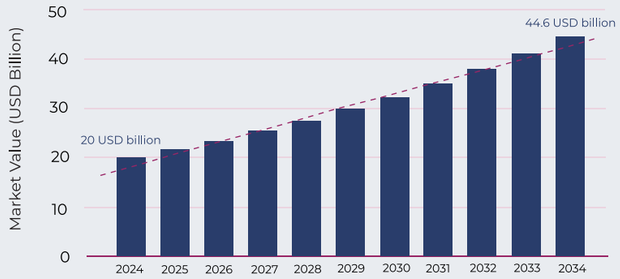


Fig. 3. Global silk market growth, 2024–2034[5]

The polyester market has also seen considerable growth and demand in recent years. Its market size was estimated at USD 118.5 billion in 2023 and is expected to grow at a CAGR of 7.3% from 2024 to 2030, with projections of it reaching USD 160 billion in 2032.[6-8] The largest market is Asia Pacific and the fastest growing market is Central and South America.[9] The market is being fueled by the increasing utilization of polyester fiber in textile, apparel, and industrial applications due to its cost-effectiveness and durability. These trends reflect the industry's response to the rising demand for polyester fibers in various sectors and the rapid growth of the fashion industry in developed countries, coupled with shifting consumer preferences for polyester blended fibers. The polyester market's expansion is also influenced by the development of environmentally preferred processes and the production of high-performance fibers.

Global Polyester Market Growth 2024–2030

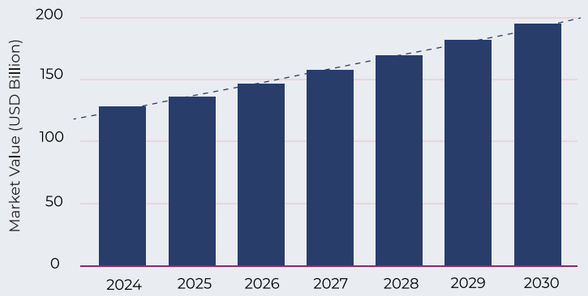


Fig. 4. Global polyester market growth, 2024–2030[10]

Fur

The total addressable market size for next-gen fur is significant especially with public perception clearly against animal-based fur.[1] This anti-fur mentality along with numerous bans on production and sale of animal-based fur has led to a market decline.[2] The global production of mink, fox, raccoon dog and other fur animals has fallen from an estimated 140 million in 2014 to 42 million fur animals in 2021.[3] While synthetic furs are rife with environmental concerns, the public is less aware of these issues. Given the unique and desirable attributes of fur, combined with this lack of awareness on environmental impact, the synthetic fur market is growing, estimated at USD 25 billion in 2022, and expected to expand at a CAGR of 8.8% between 2023 and 2031.[4,5]

Global Synthetic Fur Market Growth 2024–2031

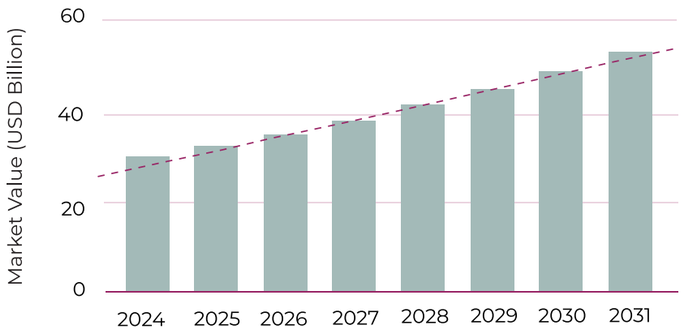


Fig. 5. Global fur market growth, 2024–2031[6]

Image credit: Ecopel
Ecopel's FLUR.

Wool/Acrylic

When we look at the market size for next-gen wool, we also should consider acrylic and polyester as addressable markets. Acrylic was developed in the 1940s as a synthetic alternative to wool, designed to mimic wool's desirable properties while being more affordable and easier to care for.[1] The technologies used to create next-gen wool, acrylic, and polyester are converging. These materials are often developed using the same advanced scientific techniques such as fermentation of plant-based ingredients and other biotechnological processes. Thus, entrepreneurs, investors, and innovators looking to recreate wool should also look to the acrylic and polyester markets, and vice versa, as part of the total addressable market. The acrylic fiber market is estimated at USD 2.7 billion in 2024, but is expected to decline to USD 2.4 billion by 2029, this could be due to strict global regulations on its production and the readily available alternative of polyester.[2]

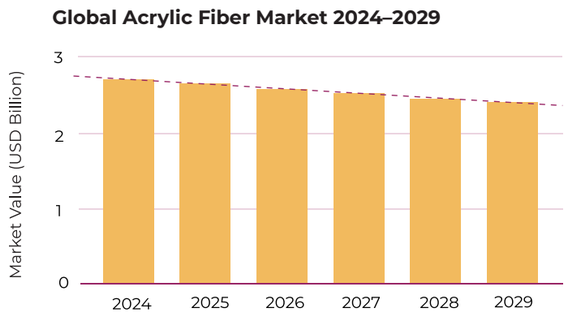


Fig. 6. Global acrylic fiber market, 2024–2029[3]

The total addressable market size for next-gen wool is significant. The global wool market size is expected to grow from USD 39 billion in 2024 to USD 49 billion by 2028, at a CAGR of 3.2%.[4] The largest market is Asia Pacific and the fastest growing market is Europe.[5] Technological advances in wool manufacturing are expected to increase productivity, and growth is likely to be further fueled by the (misleading) positioning of wool as desirable due to being "natural."[6]

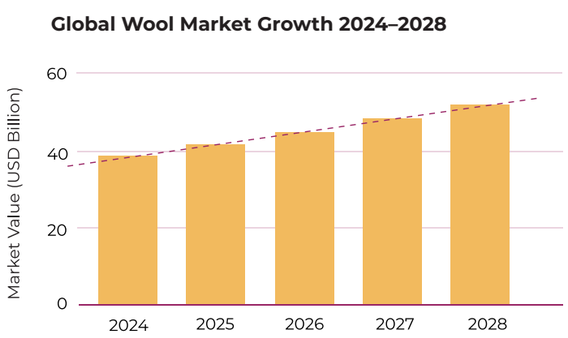


Fig. 7. Global wool market growth, 2024–2028[7]

Image credit: Marimekko
Spinnova's wood based fiber.

Down/Polyfill

When we look at the market size for next-gen down, we also should consider polyester fill as an addressable market. Polyester fill was designed as a synthetic alternative to down to offer similar comfort and insulation properties without relying on animal products. The primary material used in polyester fill is a polyester microfiber that is engineered to mimic the loftiness and softness of down. In terms of application and performance attributes, both down and polyester fill are popular choices for bedding, apparel, and outdoor gear due to their ability to provide warmth and comfort. The technologies used to create next-generation down and polyester fill are overlapping.

The total addressable market size for next-gen down is significant. The global down and feather market is estimated at USD 1.7 billion in 2024 and is expected to reach USD 2.4 billion by 2029, growing at a CAGR of 6.77% (see Fig. 8.).[1] The largest market is North America, and the fastest growing is Asia Pacific.[2] The overall usage of duck and goose feathers has increased, indirectly resulting in the broader availability of down and feathers worldwide.[3] Other sources estimate that the market may reach a significantly higher value of USD 16 billion in 2030.[4]

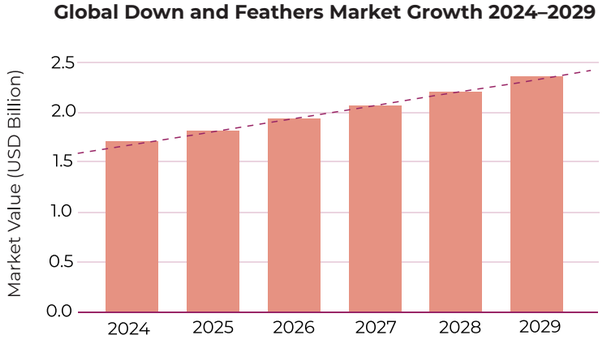


Fig. 8. Global down and feathers market growth, 2024–2029[5]

Polyester fill is a popular replacement for down, and polyester fiber's market size was estimated at USD 118.5 billion in 2023 and is expected to grow at a CAGR of 7.3% from 2024 to 2030, potentially reaching USD 160 billion in 2032 (this indicates polyester fiber generally and its many applications, not just as a fiber fill).[6-8] The largest market is Asia Pacific and the fastest growing market is Central and South America.[9]

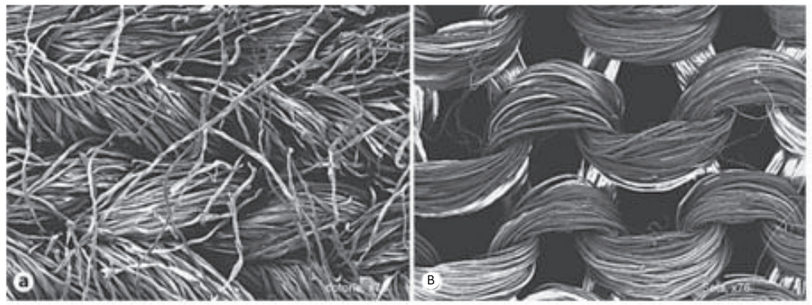
Image credit: Ponda
Ponda's BioPuff®.

SUB-CATEGORY #1 WITH LIMITED INNOVATION: SILK

Image credit: The George Washington University Museum and The Textile Museum

WHAT MAKES SILK SO SPECIAL?

Recent discoveries of silk's large environmental footprint, human rights abuses, and animal welfare concerns are inspiring scientists and innovators to develop a new generation of next-gen silk fabrics that can match silk's positive attributes without harming the planet or its inhabitants. For more information on these issues, please see our What Makes Silk, Silk? Report.



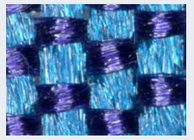
A

Fig. 9. Microscopic view of the structure of a cotton (A) versus silk (B) textile. Senti et al., "Antimicrobial Silk Clothing."[1]

For additional information on next-gen silk, please see our What Makes Silk, Silk? Reports: Original and Revisited.

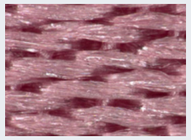
Silk is a unique and special material with desirable attributes.

- **Performance:** Silk's smooth, continuous filament gives silk yarn some of its unique properties such as strength, elasticity, and resistance to pilling. In contrast, all other natural fibers are staple fibers of discrete lengths and are bound by aggregation or entanglement.[2] These fibers may easily shed or pill under the sheer forces of abrasion.
- **Aesthetic:** The trilobal shape of silk fiber, its translucency, and its smooth surface contribute to its high luster or "shine."[3]
- **Dyes Easily:** Silk absorbs natural, nontoxic dyes easily, imparting vivid colors to its fabrics. Unlike animal silk, synthetic silk alternatives such as nylon and polyester often require disperse dyes, some of which are toxic and carcinogenic.[4]
- **Versatility:** Silk's protein-based composition makes it adaptable to different environments and thus an all-weather fabric. Silk's combination of low thermal conductivity and capacity to absorb perspiration is what makes silk fiber comfortable in nearly all weather conditions.
- **Diversity:** Silk textiles come in a variety of weights, hands, sheens, drapes, and sounds.[5]

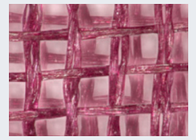


Silk Shantung

Silk 4-ply crepe

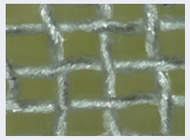


Silk charmeuse

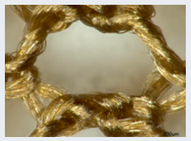


Silk plain organza

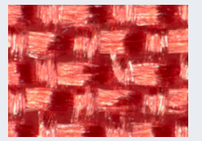
Silk crepe de chine



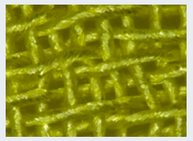
Silk chiffon



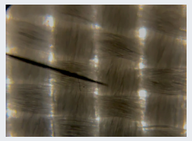
Silk mesh tulle



Silk habotai or china silk



Silk double georgette



Silk taffeta

Fig. 10. Optical microscopy of various silk fabric swatches taken at 200x magnification. Scale bar is 200 microns. MII would like to thank the laboratory of Prof. Jennifer Lewis, Sc.D. at Harvard University for equipment access to obtain these images.

HOW CAN SILK BE IMPROVED?

Silk has many positive attributes, but also several drawbacks:

- Many woven silks are delicate, requiring dry cleaning, hand washing, and steaming.
- Silk may shrink when machine washed. Spider silks are especially apt to shrink substantially after exposure to water.[6]
- Silk fabrics have low long-term heat resistance and degrade when ironed.
- Silk fabrics may bleed and stain easily.
- Silk has poor resistance to UV light. Exposure to UV sunlight can result in fading of the dyes or yellowing of white silk and can degrade the mechanical properties of silk fiber.
- Despite the high strength of silk, the fine nature of silk filaments and their use in thin fabrics, particularly knitted silk, can make them susceptible to damage like snags.
- Silk fabrics attract static, which is uncomfortable for the wearer.
- Silk has a relatively high cost compared with cotton or synthetics and is therefore often reserved for luxury apparel and accessories.
- Because it is a natural fiber, there can be fiber inconsistencies or “slubs”.

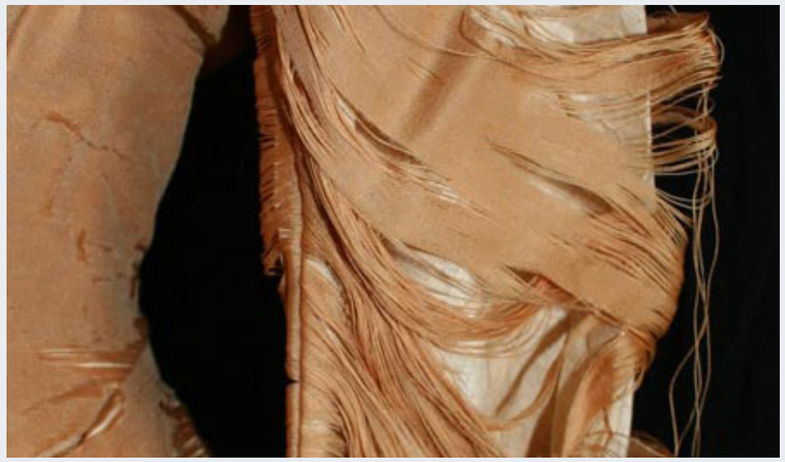


Image credit: Vintage Vixen
If treated with certain chemicals, exposed to sunlight, or otherwise stored improperly, silk can “shatter,” or lose its fiber strength and shred to pieces. Despite the strength of silk fibers, it degrades at a faster rate than other natural fibers.

KEY TARGETS FOR CREATING SILK ALTERNATIVES

With advancements in material and fiber science, we can create affordable, high performing, and more sustainable fibers that mimic the positive properties of silk and improve upon its negative attributes.

Following are attributes of silkworm silk broken down by fiber and fabric.

Fiber Properties

- **Continuous filament:** Silk is the only natural fiber that forms a smooth, continuous filament. This lends it its strength, elasticity and resistance to pilling.
- **Smooth translucent fibers:** The low roughness and high order of silk fiber and yarn contribute to its unique luster.[7]
- **Fine fibers:** The low denier, small diameter fibers are flexible, resulting in a more uniform yarn and a higher quality end fabric.
- **Strength:** The hierarchical structure, crystallinity, and alignment impart strength and toughness (see pp. 12-15 of MII’s original silk report for more information).
- **Low density**: This results in lightweight yet still strong yarns.
- **Takes dyes well:** Able to take non-toxic dyes with signature brilliance.
- **Compatible:** Suitable for use in existing knitting, weaving equipment and infrastructure.
- **Adaptable:** Versatile fibers that can be woven to create classic silk textiles.

By combining different arrangements of filaments into types and sizes of yarns and weaving those yarns into varying patterns and densities, a variety of silk fabrics are possible with unique aesthetics and performance.

Image credit: The New York Times
Actress and model Cara Delevigne wore a Stella McCartney look made from Eastman’s Naia™ for the 2024 Met Gala.

Depending on the fiber's treatment (namely how much sericin residue is left) silk can achieve vastly different aesthetics and feels, either crisp, structural, and textured (left) or fluid, glossy, and able to drape softly (right).

Image credit: Condé Nast Archive

Image credit: Kevin Winter / Getty Images

Fabric Properties

- **Soft handfeel:** Silk is pleasant to touch and wear.
- **Luster:** Silk's shine is part of its beauty.
- **Different weave capabilities:** Diverse weaving imparts a different hand and drape, e.g., taffeta hangs and tailors very differently from a sateen.
- **"Scroop":** The distinctive swishing, rustling sound, a marker of quality and authenticity, most common in taffeta.
- **"Glissade":** The signature dreamlike, sliding movement when someone is wearing silks such as charmeuse or satin.
- **"Flutter":** The light, airy movement of silks such as chiffon or georgette.
- **Comfort:** Absorbent in warm weather and insulating in cold weather; due to the triangular fiber, silk does not sit directly against the skin.
- **Diverse weights:** This enables a range of end uses.
- **Resistance to pilling and abrasion:** A desirable attribute to keep the product beautiful and new-looking for longer.
- **Dye uptake:** Able to take color brilliantly from acid dyes.
- **Naturally flame retardant:** Reduces the need for chemical treatments and additives, a benefit to consumers, workers and the environment.

Improvement Potentials

- **Decrease environmental footprint:** Although limited impact assessments exist, silk is considered one of the most environmentally damaging fibers. Mulberry farming and silk production are energy- and water-intensive, contribute to eutrophication and have a high global warming potential.[8] A life cycle assessment (LCA) conducted on raw silk produced in India revealed that silk has the highest environmental footprint across nearly all reported categories compared to cotton, nylon, or wool.[9] Synthetic silk alternatives shed microplastics that harm all animals, including humans.[10]
- **Increase UV resistance:** This will maintain a color's vibrancy and shelf life.
- **Decrease tendency for static build up:** Improve comfort for the wearer.
- **Increase mechanical properties:** This would open up high-performance applications, i.e. stretch.
- **Decrease shrinkage:** This would make care requirements for the user less demanding.
- **Increase launderability:** Anything that makes fabric care easier for your end user is of benefit.
- **Decrease cost:** Silk's high cost currently limits it to the luxury sector.
- **Increase stain resistance:** A desirable attribute for many end users in many applications.
- **Increase durability:** Beautiful and durable is a win-win.
- **Improve fiber consistency:** This would create more uniformity and avoidance of slubs in the yarn and fabric.
- **Avoid harm to animals:** Billions to trillions of silkworms are killed every year in silk production, and so called "peace silk" is not free from ethical dilemmas.[11,12]

Next-Gen Silk (left) vs. Silkworm Silk (right)

Image credit: Zoonar GmbH / Alamy

Image credit: AMSilk

A true silk mimic needs to retain the luxurious properties—especially the look and feel—of natural silk in order to be successful.

INNOVATORS: NEXT-GEN SILK

We are including 14 companies in this report who are at various stages of R&D and some that have been commercial for quite some time but continue to innovate with sustainability as a driving force. This is why you will see start-ups like Kintra Fibers on the same table as Eastman and Lenzing.

Next-Gen Silk Textile/Fiber Producers

Company	Material/ Fiber name(s)	Year Founded	HQ	Main Input	B2B or B2C	Stage	Website
Alt Tex	N/A	2019	CAN	Plant-derived	B2B	R&D	www.thealttex.com
AMSilk	Biosteel® and Protein Fiber	2008	DEU	Microbe-derived	B2B	Commercial	www.amsilk.com
Circ	N/A	2011	USA	Recycled Material	B2B	Commercial	www.circ.earth
Eastman	Naia™	1920	USA	Plant-derived	B2B	Commercial	www.eastman.com
Ettitude	PLNTsilk™ and Clean Bamboo®	2014	USA	Plant-derived	B2B & B2C	Commercial	www.materials.ettitude.com
Kintra Fibers	Kintra	2018	USA	Plant-derived	B2B	R&D	www.kintrafibers.com
Lenzing	TENCEL™ and ECOVERO™	2004 Lenzing acquires Tencel brand	AUT	Plant-derived	B2B	Commercial	www.lenzing.com
Nanollose	Nullarbor®	2014	AUS	Microbe-derived	B2B	Near Commercial	www.nanollose.com
Orange Fiber	N/A	2014	ITA	Plant-derived	B2B	Commercial	www.orangefiber.it
Renewcell[11]	N/A	2012	SWE	Recycled material	B2B	Commercial	www.renewcell.com
Rubi Laboratories	N/A	2020	USA	Other	B2B	R&D	www.rubi.earth
Spiber	Brewed Protein™	2007	JPN	Microbe-derived	B2B	Commercial	www.spiber.inc
Spidey Tek	N/A	2015	USA	Plant-derived	B2B	R&D	www.spideytek.com
Tandem Repeat	Squitex	2017	USA	Microbe-derived	B2B	R&D	www.tandemrepeat.com

SUB-CATEGORY #2 WITH LIMITED INNOVATION: FUR

Image credit: Todd Heisler / The New York Times

WHAT MAKES FUR SO SPECIAL?

Fur is a unique material from both a design and scientific perspective.

Diversity of Applications

- Fur has multiple applications including apparel such as coats, linings, and trims; accessories like bags, hats, ear muffs, scarves, boots (shell and lining), and keychains; and home products like blankets, throws, pillows, and rugs.
- Fur is one of the few materials which can simultaneously conjure luxury and rustic images. We may see ermine draped over the shoulders of kings and queens or envision the protective pelts worn on the American frontier. It is luxurious and warm. It can be playful or dramatic.

For additional information on next-gen fur, please see our What Makes Fur, Fur? Report.

Elicits Emotion

- Perhaps no other material comes with such emotional attachments as fur. When we see a soft-looking, long-haired, or thick-pile fur, we have an involuntary urge to touch it. Our emotions are stirred; it speaks to us through our senses. Humans are drawn to fur, perhaps more than any other material. It seems to promise physical and emotional protection.
- How people see fur also varies widely and is an emotional subject. Some see fur as the height of luxury and aspiration while others see it as the ultimate human disregard for animal suffering.

Fur is unique in that it can signify luxury and can also be a practical insulator against harsh weather conditions.

Image credit: Heritage Images / Getty Images

Image credit: Collection of the Smithsonian National Museum of African American History and Culture

Variety of Aesthetics and Hand-Feel

- Animal-based fur comes from a variety of animals and thus is also available in a variety of colors, textures, and hand-feels. Fur's texture can be curly like the sheared coat of a lamb or straight and silky like a rabbit.

From left to right (with credits): **Mink** (Mattia Dantonio / Alamy), **Fox** (Oksana Korniyenko / Alamy), **Lynx** (imageBROKER.com GmbH & Co. KG / Alamy), **Mongolian Lamb** (Martin Norris Studio Photography / Alamy), and **Chinchilla** (Harrods of London) furs.

- One cannot overlook the complexity and dimension of animal fur when trying to parse out why it is so special. Most animal furs are multi-layered: a short dense undercoat and a longer protective layer on top. Combined, these layers add visual diversity, appeal, depth of color, and contribute to the overall handfeel experience.

- Fur is highly customizable. Some furs look exactly like the original coat from the animal while others are dyed in "natural" or unnatural bright fashion colors. Patterns can appear to be sculpted into fur through patchwork, using multi-colors, changing direction of hair or nap within a finished product by piecing and, of course, trimming the hair to design specifications. Fur can also be printed to mimic other animals and their coats.

Fur can be manipulated (or left alone) to achieve a variety of aesthetic effects.

Image credit: Wikimedia Commons

Image credit: Yannis Vlamos / GoRunway.com
An antelope skin dress by Fendi.

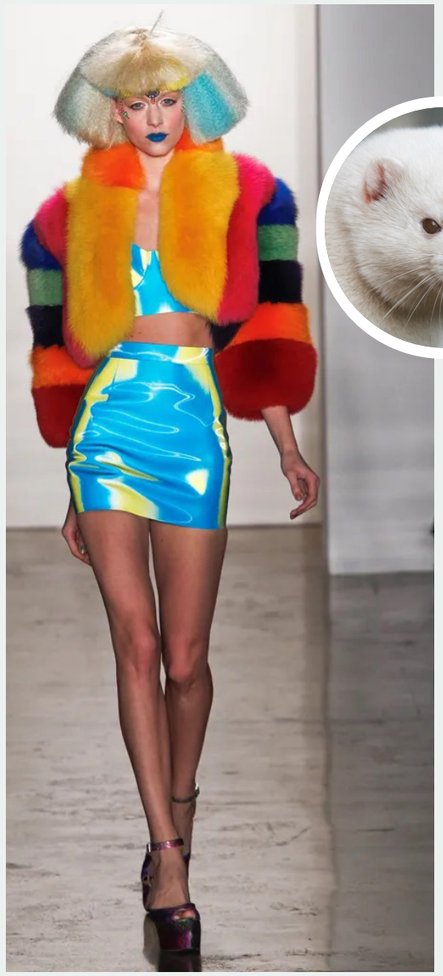


Image credit: We Animals Media

Image credit: Filippo Fior / GoRunway.com
Rainbow dyed mink jacket from Jeremy Scott's 2012 collection.

Image credit: We Animals Media

Image credit: Matt Reichel
A woman from the Arctic wears a suit made from Beaver to keep warm.

Functionality

- Fur is one of the most thermally insulating animal-based materials. It keeps the wearer both warm and dry.
- Animal-based fur can get wet, like getting caught in the rain, without concern for ruining the material. A true soaking requires a trip to the fur care professionals. Similarly, synthetic fur can also get wet and requires drying naturally in a warm and dry environment.
- Animal fur is naturally flame retardant while many synthetic furs require added flame retardants. Protein-based fibers like wool and fur have limited flammability and can often be exempt from flammability testing requirements.

Structure

- Fur contains both skin and fiber, unlike other animal-based materials which are either a skin or a fiber.
- Synthetic fur is a pile fabric which mimics this structure.

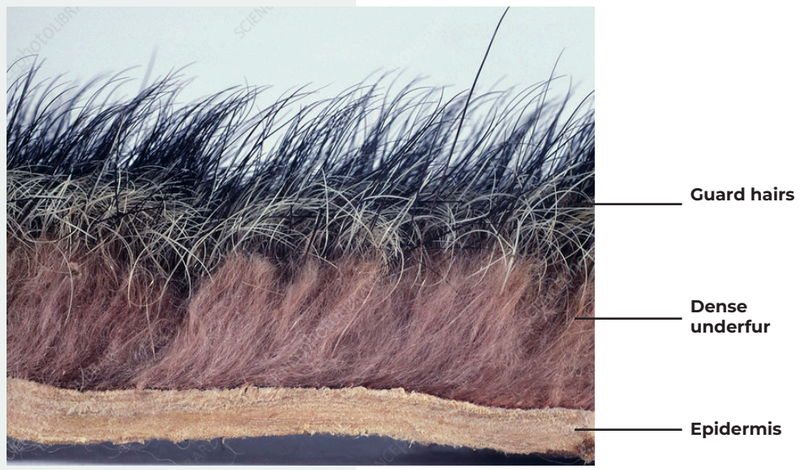


Image credit: British Antarctic Survey / Science Photo Library
A cross-section of a seal pelt.

HOW CAN FUR BE IMPROVED?

Animal-based fur and synthetic furs are rife with animal welfare and sustainability issues. Most animals raised for their fur spend their entire lives in cramped, unsanitary, and inhumane conditions. There are few regulations around the slaughter of fur animals, giving producers leeway to favor cheap killing methods such as electrocution, gas, poison, suffocation, and skinning animals alive (all methods that do not damage pelts). Public perception is overwhelmingly against animal-based fur and animal rights advocates will continue to advocate for additional fur bans and moving consumer sentiment against fur. We have the opportunity through science and technology to develop new materials which mimic the valuable aspects of fur while also removing the negative externalities. There are also ways new material development can improve on the performance aspects of animal-based and synthetic fur. For more information on the environmental and animal welfare issues with fur, please see our What Makes Fur, Fur? Report.

Inefficient Sourcing and Manufacturing

- Animal-based fur is a highly inefficient process. In factory farms, the source of the vast majority of animal furs, the process requires the breeding, care, feeding, and slaughter of animals. In wild trapping, the system is even more inefficient, requiring extensive work in carrying large numbers of traps through the wilderness, laying traps for wild animals, monitoring those traps, and carrying the deceased animals back from the wild.

- Manufacturing fur products from small animals is also very inefficient and time intensive. It takes 150-300 chinchillas or 50-60 minks or 15-40 foxes to make a full length coat. There can be a lot of waste when using animals because the furrier will want the patterns to line up and have consistent color around the body. Needless to say, small parts of the animal – head and legs will also be waste as they are too small to use and the fur tends to be of a shorter length and texture in those areas.[1,2]

Fur's Contribution to Global Pandemics

- During the Covid-19 pandemic, there was a great deal of culling due to concerns about disease passing between animals and humans. This resulted in a decrease in the availability of mink and other furs. Up to 35% of the raw mink pelt trade was eliminated due to Covid-19 outbreaks at mink farms.[3] Moving away from animal-based materials to plant-based sources will remove the risks to the supply chain and global health from pandemics and other zoonotic diseases.

Image credit: BioFluff

Improvement on Performance Metrics

- Thermal properties are not practical for many climates - next-gen fur can tune performance properties using custom composition, thereby making fur less season specific.
- The properties of fur, such as strength and fiber length, are biologically determined by the species of animal and tanning process. Innovators are figuring out how to mimic these characteristics and expand beyond them, opening up the potential for more creativity and unique designs.

Extensive Care

- When cared for properly, animal fur is a high maintenance product. Animal hides can dry out and become fragile or brittle. Specialized cleaning professionals are always recommended for animal-based fur products. Next-gen fur can significantly reduce the care and maintenance required.

Expense

- Despite common misperceptions, animal-based fur is not a good investment. Fur products do not appreciate in value over time. In fact, they are much like cars or boats – they depreciate the moment you take them off the lot. They can lose 18-25% of their value annually.[4] Through more efficient manufacturing, next-gen fur can be created to meet many price points.

Next-gen furs using sustainable and renewable inputs along with green chemistry will end the animal-cruelty associated with fur production and have the potential to decrease negative environmental impacts while meeting the desirable aspects of animal-based fur.

Animal-Based Fur Maintenance is High Effort:[5]

- Cold storage is recommended with a consistent temperature of 50-60°F/10-15°C and 45%-55% humidity, this slows down the degradation process of fur.
- Furs should be wrapped in a cotton cloth with plenty of room between each garment. Plastic bags or crowded closets prevent air circulation causing the pelts to dry out or crack.
- Fur coats must be hung on a broad-shoulder, sturdy hanger in a non-cedar wood closet without mothballs, as these would dry out and damage the fur.
- If fur gets caught in a downpour and is completely soaked through, it will need immediate professional fur care.
- Mongolian lamb and long hair goat garments require a special combing process.
- Fur accessories such as hats, scarves and neck warmers require special cleaning attention to remove oils and make up.
- Mink requires cleaning every other year, a fur coat should be professionally cleaned and conditioned often, due to exposure to the elements and airborne pollutants, all of which can damage and degrade the fur. Dry cleaning is not recommended.

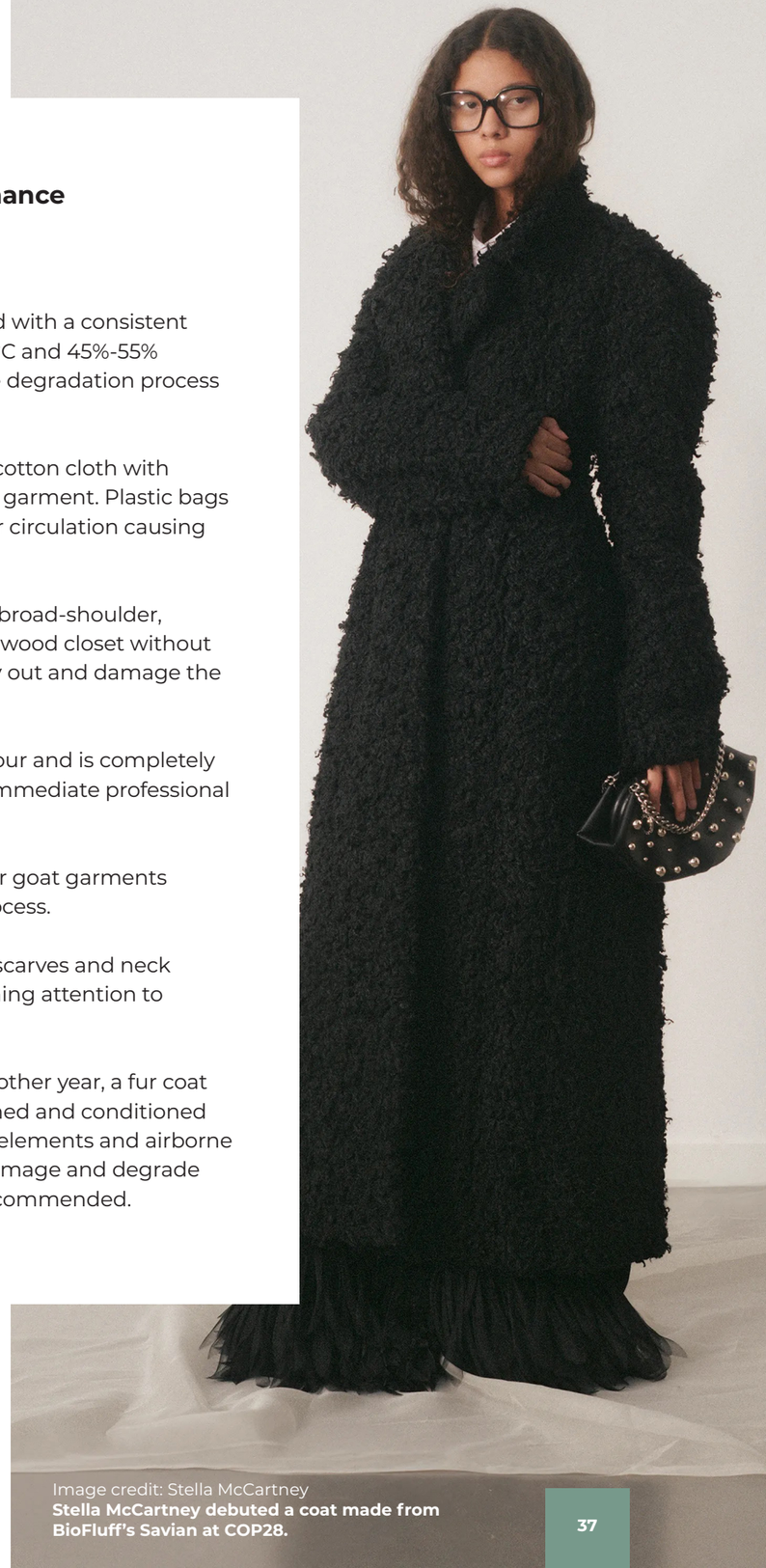


Image credit: Stella McCartney
Stella McCartney debuted a coat made from BioFluff's Savian at COP28.

KEY TARGETS FOR CREATING FUR ALTERNATIVES

In order for next-gen fur to be successful, it needs to improve upon the existing material. While all next-gen furs should (by definition) have a lower environmental impact without the animal-cruelty, these factors alone are not sufficient for success. Next-gen furs must also improve on the performance attributes of fur and be cost-competitive.

Consumer research has found that status-seeking consumers want synthetic fur options to look as real as animal fur, and this type of consumer has a high purchase intention towards fur.[6]

Environmental Targets

The structure and composition of the material should lead to an environmentally preferable product compared with incumbents. Focus on these key areas:

- Material inputs should be majority bio-based or recycled.
- The product should be recyclable, biodegradable, or otherwise responsibly disposed of at end-of-life.
- Microfiber shedding and release should be mitigated as much as possible through design and manufacturing.
- Innovators should focus on green chemistry for dyes, additives, and treatments.
- Innovators should target reductions in carbon emissions, water use, and land use among other environmental impact categories during production.

Tunability and Variety

It is critical for next-gen fur innovators to understand that to be successful they must be able to offer a portfolio of fur product offerings for adoption by brands. Animal-based and synthetic furs have a wide variety of colors, prints, patterns, textures, and lengths. Next-gen materials will need to meet this variety of options but also have the potential to expand beyond, akin to the novel colors and textures offered by current-gen synthetic fur. Brands can get frustrated when new solutions don't provide them the choices they are accustomed to. While brands may understand that innovation takes time, innovators will need to be thinking about meeting those expectations long-term. For this industry to succeed it will need a suite of pile fabrics offering the look, handfeel, and warmth of the incumbent textiles.

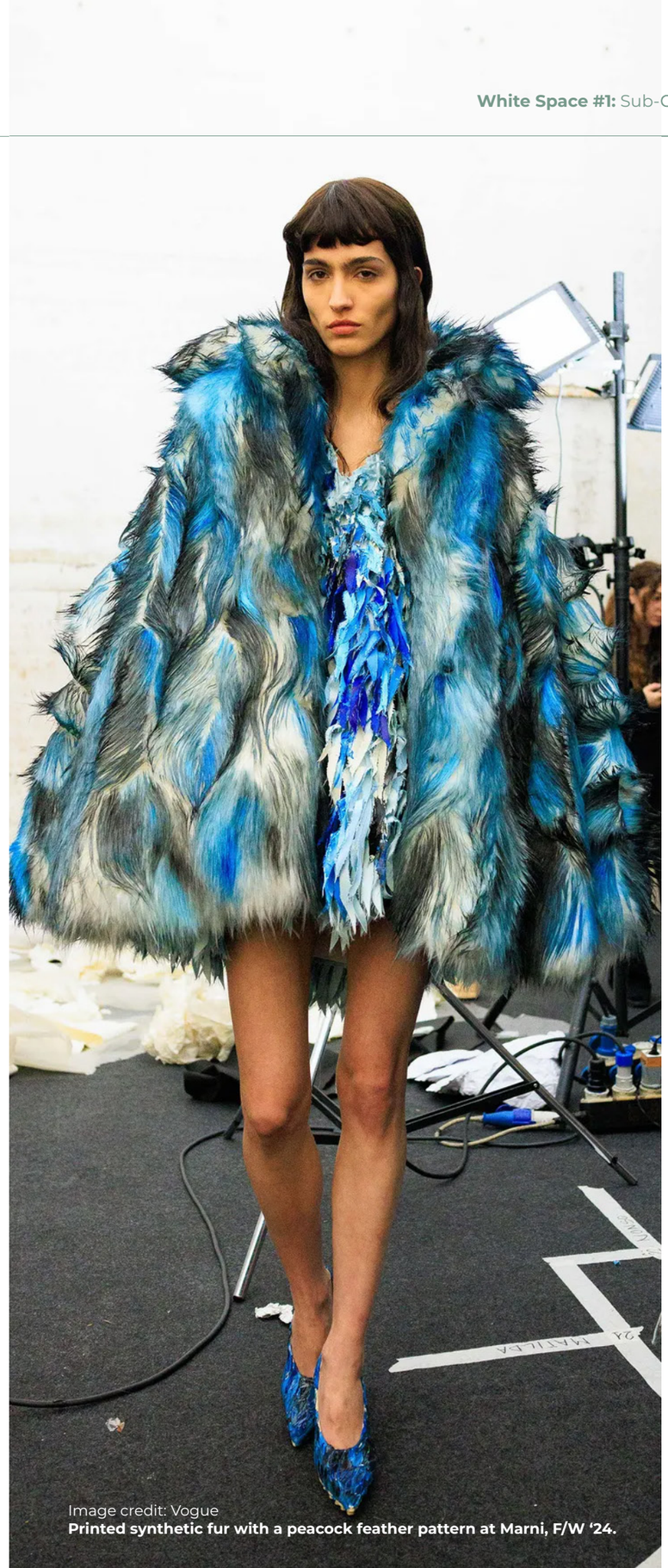


Image credit: Vogue
Printed synthetic fur with a peacock feather pattern at Marni, F/W '24.

Color, Print, and Pattern:

- The textile must be able to accept non-toxic dyes without crocking, bleeding, or fading.
- On offer should be natural colors that mimic the animal and/or dyed fashion colors.
- Color tipping or piecing multi-color fur (like patchwork) can inspire design teams.

Textures:

- Luster, softness, and handfeel are critical attributes. The material should be similar to the incumbent animal or, at minimum, current-gen synthetic furs.
- Tight curls like shearling or loose silky curls like the hairs found in Mongolian sheep are always popular with fashion.
- Low thick piles that are soft and velvety with dense fiber placement and sheared to one length, like beaver, are timeless and have broad product application.

Lengths and Diameter:

- Generally speaking, fibers need to be continuous filament, or of a long staple length to work as a pile.
- Innovators should consider the fiber diameter, length, taper, density (or placement of fibers) and texture needed to replicate the desired material.
- Fur comes in a variety of lengths. For example, rabbits, mink, and chinchillas have flat, short, shiny hairs. Foxes have long fine tapered hairs with a dense undercoat; and a raccoon's coat is long and thick with comparatively coarse hair.

Backings/Linings

Pile fabrics, by necessity, have backings. One should always consider the end use or application for their material when choosing a backing and work with a manufacturing partner to confirm viability. Also consider how the backing will affect your product's sustainability goals/claims – biodegradability, recyclability, etc.

- It is important to understand how your material will be handled at the factory in order to be cut and sewn. The backing should be a stable textile that doesn't unravel easily.

- If your textile is to be used as a lining (potentially putting it against the wearer's skin), it is advisable to know if it is hypoallergenic and color safe (will not crock).

- Additionally, if it is to be used as a lining, breathability/moisture management should be similar to, or better than, the incumbent.

Image credit: Gucci
Gucci's Princetown loafer slide with synthetic fur lining.

Elicit Emotion

The emotional appeal of fur should not be underestimated! As mentioned previously in this report, animal fur and incumbent synthetic furs are known to awaken human emotions. It starts with our eyes and then our brains quickly notify our fingers to touch.

- Performance is important of course, but give due focus and time to aesthetics and haptics.
- Emotional attraction will drive the purchase – beginning with the brand and down to the consumer. A 2019 study of fur consumer behavior in Germany found that aesthetic **appearance was the top purchase motivator for animal fur consumers**, despite knowledge of fur scandals, followed by functionality.[7]
- Next-gen furs should be so inviting that it is hard not to touch!

Next-Gen Fur (left) vs. Animal Fur (right)

Image credit: Volodymyr Burdiak / Alamy

Image credit: Ecopel

Wear, Laundering, and Care

As discussed previously, animal-based fur has burdensome care requirements. Any improvement in reducing maintenance is an opportunity to improve on the product. The easier to maintain, the better…and always include care instructions.

- Pleasant or no smell should come from the textile.
- Flame retardancy should meet international standards for specific applications.
- Having hypoallergenic properties is valuable when considering furs are often used as linings in coats and footwear or trim on hoods and in close proximity to skin.
- Thermal properties are usually expected when purchasing fur apparel and accessories.
  - Consumers surveyed in China said the most sought-after qualities in animal fur are: functionality and warmth (top), appearance, and the material and feel of the product (bottom). Meanwhile, Chinese consumers who don't wear fur feel it is not functional or practical due to being too hot, not washable, and not suitable for daily wear.[8]
- Furs that can simply be 'shaken out' to reorganize and fluff the nap would be a plus.
- Reduce the need for specialist cleaning; home laundering is desirable.
- Reduce the need for special storage. It is critical to perform testing to ensure air, light, dust do not drastically alter the fur.

Image credit: BioFluff

Consider a Variety of Applications

"Fur" is used to elevate and add novelty to home and fashion collections. The great variety of fur in the marketplace captures many different end uses and innovators should explore these broad applications.

- Home goods include blankets, rugs, pillow shams, and bedding.
- Fashion and accessories capture a wide array of products for men and women in the luxury and mass markets.
- The outdoor apparel market should be a primary target for using environmentally preferable textiles.
- Childrens apparel, furnishings and toys are often overlooked. They have great potential for next-gen adoption.

Remember Your Manufacturing Partner

Next-gen and synthetic fur fabrics are highly specialized. When creating a next-gen fur textile, remember that animal furs often have multi-lengths and multi-layers of hair that add to its luxuriousness and performance. Therefore, it is important to find a manufacturing partner practiced in this textile set up.

- Development work will be accelerated if working with a fur manufacturing partner.
- Tapping into existing synthetic fur manufacturing increases the possibility of a quicker scale-up and brand adoption.
- Manufacturing partners will be able to address if properties such as tensile strength and crocking are sufficient for manufacturing and garment use requirements.
- Identify cut-and-sew factory partners early on to ensure your textile can successfully go through the existing cut/sew/trim process.

INNOVATORS: NEXT-GEN FUR

There are currently 7 companies creating next-gen fur as an end product or creating a fiber which can be turned into a next-gen fur. As with all next-gen materials and fibers, these innovations are a new class of products. They are more sustainable than the incumbents—in this case animal-based fur and synthetic fur— and they offer new design opportunities.

Next-Gen Fur Textile Companies

Company	Material/ Fiber name(s)	Year Founded	HQ	Main Input	B2B or B2C	Stage	Website
BioFluff	SAVIAN	2022	USA, FRA	Plant-derived	B2B	Early stage commercial	www.bio-fluff.com
BIOFUR®	Biofur®	2023	USA	Plant-derived	B2B	R&D	www.biofurworld.com
DevoHome	Hemp Fur	2008	UKR	Plant-derived	B2B & B2C	Commercial	www.devohome.com
ECOPEL	KOBA®, New Generation, Cannaba Wool and FLUR™	2004	CHN	Recycled and Plant-derived	B2B	Commercial	www.ecopel.com

Next-Gen Fur Fiber Companies

Company	Material/ Fiber name(s)	Year Founded	HQ	Main Input	B2B or B2C	Stage	Website
Lenzing	TENCEL™ Lyocell	2004 Lenzing acquires Tencel brand	AUT	Plant-derived	B2B	Commercial	www.lenzing.com
Metsä Spring	Kuura™	2018	FIN	Plant-derived	B2B	R&D	www.kuura.io
Spiber	Brewed Protein™	2007	JPN	Microbe-derived	B2B	Commercial and R&D	www.spiber.inc

SUB-CATEGORY #3 WITH LIMITED INNOVATION: WOOL

Image credit: The George Washington University Museum and The Textile Museum

Although wool primarily comes from sheep, several other animals also produce wool fibers.

1. **Sheep Breeds:** Providing different qualities of wool are Merino, Rambouillet, Blue Faced Leicester, and Corriedale. Shetland sheep, from the northern islands of Scotland, are a small breed and provide a very particular fuzzy yarn that is thought to improve with age.

2. **Goats:** Cashmere and mohair are types of wool obtained from different breeds of goats. Cashmere comes from the Kashmir goat, while mohair is produced by the Angora goat.

3. **Alpacas:** Alpaca wool is softer and less prickly than sheep's wool, coming from the alpaca, which is native to the Andean region of South America.

4. **Llamas:** Similar to alpacas, llamas also produce a soft and durable fiber, though it is typically coarser than alpaca wool.

5. **Rabbits:** Angora wool comes from Angora rabbits and is known for its softness and fine fibers.

6. **Camels:** Camel wool is another type of fiber used in making textiles, particularly valued for its thermal insulation properties.

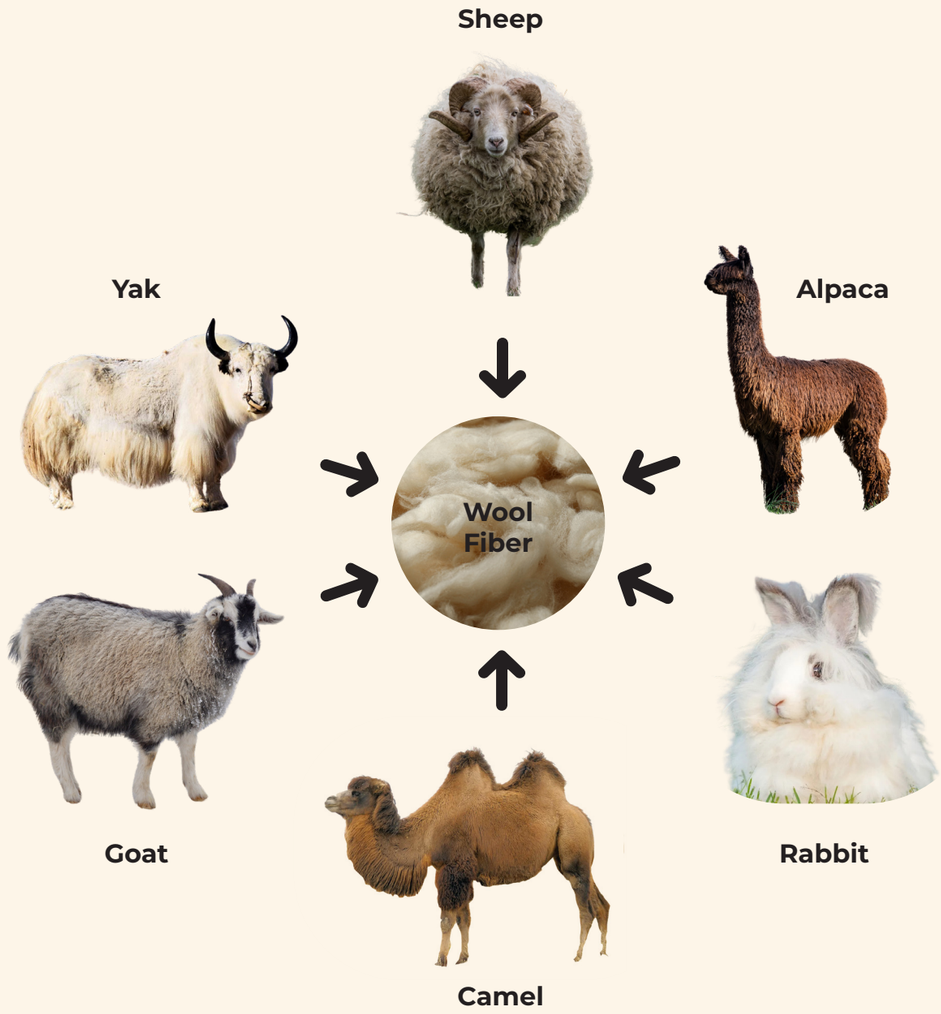


Image credits: Sheep: Jo-Anne McArthur / We Animals Media; Alpaca: Suri & Company; Rabbit: Shutterstock; Camel: Shutterstock; Goat: Marcel Langthim / Pixabay; Yak: Getty Images; Wool Fiber: Liudmila Chernetska / iStock by Getty Images.

WHAT MAKES WOOL SO SPECIAL?

Diversity of Applications

- **Variety:** Wool comes from a variety of different animals resulting in different fiber lengths, thicknesses, textures, and colors. Fiber lengths can vary between 2 to 15 inches depending on the breed of sheep. The variety of yarn qualities lends itself to a variety of products used in the fashion, accessories, footwear, home, and auto industries.

- **Wool can be both luxury and utilitarian:** We see it in cashmere sweaters and woven apparel including fine suitings. Wool yarns are also soft and comfortable enough to be worn as long underwear. Conversely, given its rugged durability, coarse woolens and melton are popular for sportswear, outdoor apparel, coats, home goods, and upholstery.

- **Handfeel:** Wool has contrasting hand feels ranging from super soft and lightweight to coarse and board-like. We see sweaters that are seemingly knit with air and baby-soft blankets. Clever stitchwork creates a multitude of patterns in sweaters (rib and cable being among the most classic). Twisting multi-colored yarn creates its own color melange. Different woven wools can have a clean “face” (when the exterior surface is smooth, not hairy) or they can be brushed to give a nap to the surface.

- **Seasonless:** In the last decade, we see cashmere as having a year-round presence. Originally part of “Resort” collections offered during the Northern Hemisphere’s winter months in the fashion industry, cashmere has been democratized and made seasonless by increasing volume and lowering prices.

Wool can be both luxury and utilitarian.

Image credit: Brooks Brothers

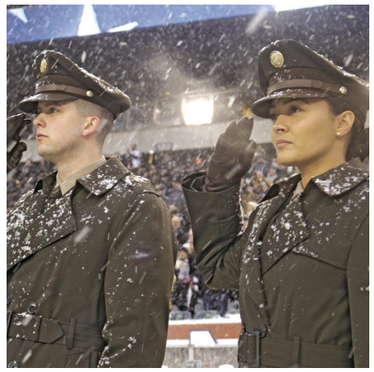


Image credit: Ron Lee / U.S. Army

Elicits Emotion

Of all the wool yarns, cashmere probably makes us ‘feel’ the most. It is generally considered the most luxurious of the wool fibers. It is at once silky, soft, warm, and feels good against our skin.

The coarser yarns can be knitted or woven into fabrics like wool melton, and can make one feel they are protected and ready for a walk through the brambles on a drizzly, cold day.

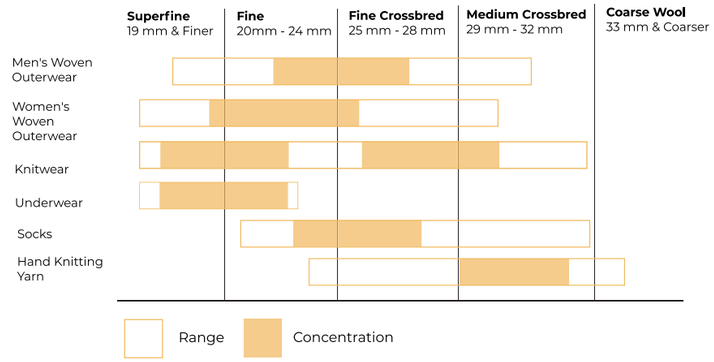


Fig. 11. End uses for wool by micron range. Recreated from the original by American Sheep Industry Association.[1]

Image credit: Botanè
Botanè’s plant-based cashmere alternative in production.

Performance

- **Insulation:** Wool fibers have natural crimps and air pockets that trap heat, providing excellent insulation. This means they keep you warm in cold weather while also being breathable and preventing overheating.
- **Moisture-wicking:** Wool can absorb moisture from the air without feeling damp. It moves moisture away from the skin, keeping you dry and comfortable. Some weaves or knits are water resistant.
- **Odor resistance:** Wool has natural antimicrobial properties, which help prevent the growth of odor-causing bacteria.
- **Durability:** Wool fibers are resilient and elastic, meaning they can withstand repeated stretching and bending without losing their shape. Wool garments are often long-lasting and can withstand a lot of wear and tear.
- **Wrinkle resistance:** Wool has natural/minimal elasticity, which helps it retain its shape and resist wrinkles. This makes wool clothing low-maintenance and easy to care for.
- **Flame resistance:** Wool is naturally flame-resistant, meaning it is less likely to catch fire compared to other materials. It also tends to self-extinguish if it does catch fire, further reducing the risk of injury.
- **Biodegradability:** Wool, in its natural state, is a renewable and biodegradable material (although that commonly changes through processing and the application of dyes or finishes).

Fishermen from the Aran Islands wore “Aran jumpers” which in later years came to be known as “fisherman sweaters”. These practical sweaters made from sheep’s wool allowed for freedom of movement, provided warmth and, due to the naturally occurring lanolin in the sheep’s wool, were water repellent.

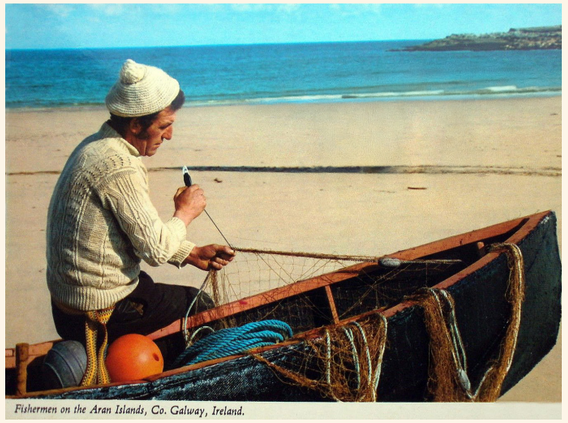


Image credit: John Hinde Archive
A postcard picturing a fisherman mending his net on a beach on the Aran Islands in County Galway, Ireland.

Image credit: WoolSpinEwe / Etsy
From left to right; Merino, Rambouillet x Suffolk x Texel, Romney raw wool.

Structure

Wool fibers have a complex structure that gives them their unique properties.

- **Cuticle:** The outer surface of wool fibers is made up of overlapping scales known as cuticle cells. These cells are responsible for wool’s ability to felt, as they can slip over each other in one direction but not the other. The cuticle cells have a waxy coating that makes wool water-repellent while still allowing it to absorb water vapor.[2]
- **Cortex:** The main body of the wool fiber, called the cortex, constitutes about 90% of the fiber’s structure. The arrangement of these cells affects the fiber’s crimp, which in turn influences the wool’s springiness and insulation properties.[3]
- **Cell Membrane Complex:** This surrounds the cortical cells and acts like mortar holding bricks together. It contains proteins and waxy lipids and enables the fiber’s ability to easily absorb dyes.[4]
- **Macrofibrils and Microfibrils:** Inside the cortical cells are macrofibrils, which are composed of bundles of microfibrils. These microfibrils are embedded in a matrix that contains high sulfur proteins, contributing to wool’s absorbency, fire-resistance, and anti-static properties.[5]
- **Twisted Molecular Chain and Helical Coil:** Within the microfibrils are twisted molecular chains, containing protein chains coiled in a spring-like structure. This coil is the smallest part of the wool fiber and is what gives wool its ability to flex and bounce back, which is what makes wool a unique and coveted fiber helping garments to retain their shape and avoid wrinkling.[6]

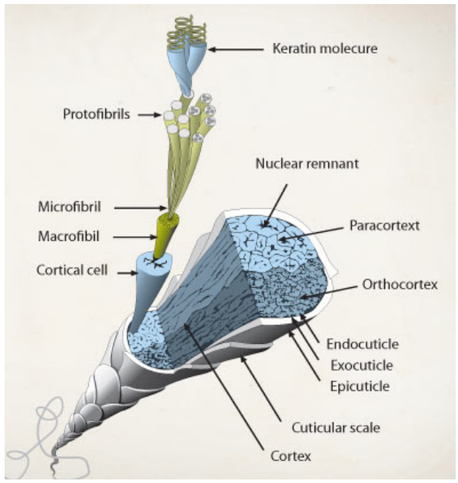


Image credit: SmartWool

Image credit: King Textiles
Wool melton selvedge.

Special Textile Feature: Wool Melton

Wool melton is a popular outerwear fabric long used for peacoats and capes. It is a dense, tightly woven material known for its smooth, felt-like surface and can be quite thick. Wool melton is the result of a fabric finishing process. Once the wool is woven in a very tight weave, the fabric undergoes a process called milling, where it is treated with heat, moisture, and agitation. This process causes the wool fibers to shrink and mat together, enhancing the fabric's thickness and strength. It is then napped and sheared to give it an even hand on the surface and then undergoes final pressing and finishing. It can be made to look refined for luxury apparel or utilitarian for military use.

Performance Features of Wool Melton

Durability and warmth:
Its tight weave and thickness make it very durable and ideal for cold weather.

Water resistance:
While not fully waterproof, the dense weave offers resistance to water, making it a good choice for light rain conditions.

Unraveling:
Interestingly, when cut, it doesn't fray or unravel easily, which simplifies the finishing of garments.

Image credit: No Man Walks Alone
A modern take on a CPO jacket, made from wool melton.

HOW CAN WOOL BE IMPROVED?

Wool, while a versatile and popular material, faces several challenges. Wool faces numerous practical issues such as being scratchy, pilling, and requiring high-maintenance care. Wool also contributes to significant environmental issues such as high GHG emissions, water use, chemical use, and contributing to lack of biodiversity. Animal welfare issues, such as painful live lamb cutting (mulesing) and high lamb mortality and slaughter, persist. Next-gen alternatives offer the opportunity to mitigate or solve all of these problems.

Practical Problems with Wool

- **Scratchy:** Wool can be scratchy, irritating to skin, and can lead to allergic reactions.
- **Pilling:** Knitted wool and some wovens can pill, due to uneven yarn lengths or broken yarns making a garment or product look less expensive and leading to early disposal.
- **High care and maintenance:**
  - Machine washing is generally not recommended. Temperature settings and cycle agitation can cause shrinkage, mis-shaping of the garment, or yarn pilling.
  - Dry cleaning can be expensive and not all dry cleaners use "green" methods.
  - Hand washing might shrink the product, colors might bleed, and is inconvenient.
  - Moths will show up if not stored properly and will create holes requiring mending.

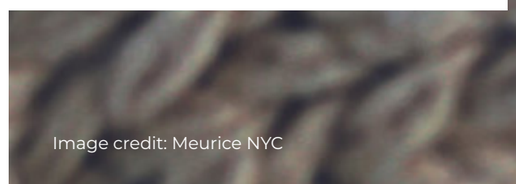


Image credit: Meurice NYC

Wool's Contribution to Environmental Damage

- **High GHG emissions:** Ruminants like sheep emit significant methane, contributing to global warming, with wool's greenhouse gas emissions ranging from 8.9 kg to 41 kg CO2e per 1 kg of raw wool, the equivalent of driving for 22 to 100 miles.[7-9] An Australian merino wool sweater creates 27 times more GHG emissions than the same one made from Australian cotton.[10]

Wool's GHG Emissions Are Significantly Higher Than Other Fabrics'

Carbon dioxide-equivalent emissions in kilograms per 264 grams of fiber for seven different fabrics.

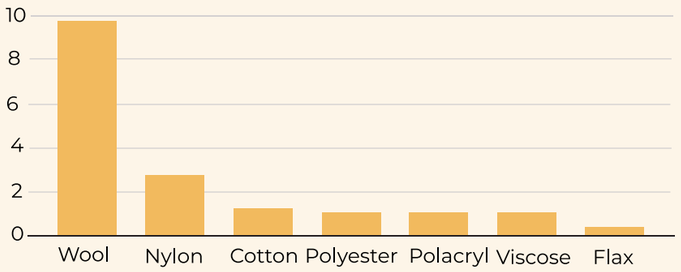


Fig. 12. One study's estimate of greenhouse gas emissions per 264g of fiber for seven different fabrics. Study by Ecoinvent, original graph created by Vox.[11,12]

- **Land use, water use, chemical use, and eutrophication:** Wool production demands substantial land resources, with wool requiring 467 times more land than cotton to produce one bale in Australia.[13,14] It is also a water-intensive fiber, from farm to fertilizer to cleaning and dyeing use requirements. Extensive chemical use during scouring (cleaning) poses pollution risks. Industry bodies themselves report that "wool scouring produces a highly polluting effluent stream which is very difficult to degrade by biological microorganisms."[15] Biological waste in the form of fecal matter and sheep dip[16] (toxic chemicals used to reduce parasites on sheep) present further problems, contaminating waterways and soil near farms, creating eutrophication and posing significant health threats for a variety of animals including humans.

- **Biodiversity:** Habitat loss through deforestation and land degradation are among the greatest threats to biodiversity, and animal agriculture is the leading cause of habitat loss.[17,18] So even in cases where better practices are in place such as regenerative wool farming, sheep are still a threat to native wildlife and ecosystems. In many areas farmers are allowed to kill wild animals such as kangaroos and coyotes that are considered "pests".[19] The vast areas of land required by ruminants could be used instead for more effective native carbon sequestering ecosystems.

Animal Welfare Concerns

- 672 million animals are used every year in the production of fine wools for the fashion industry alone.[20]
- 50% of sheep used in the wool industry are killed for their meat. Wool and meat are necessary economic co-products for the industry. (See right.)
- Shearers are often paid by volume, not by the hour, incentivizing workers to de-prioritize animal welfare for the sake of efficiency.
- Significant wool production involves "mulesing" or "live lamb cutting," a painful procedure for the sheep.
- Animals used for wool are often selectively bred to grow an excess of wool which is both uncomfortable for the sheep, as it can be heavy and animals are unable to regulate body temperature, and dangerous, as flies lay eggs in the folds of their skin and, once hatched, literally eat them alive (known as "flystrike").
- While lambs should be born in the spring, it is cheaper for farmers to engineer their births in the winter. As a result, 10-15 million lambs die in the first 48 hours of life from hypothermic exposure, starvation, or neglect.[21]
- More than any other animal material, wool is misrepresented as humane and beneficial for the animal.

Expense

Wool and cashmere yarns are expensive with good reason when you consider the supply chain and what is required to raise and care for large herds, not to mention the resource-intensive shearing and cleaning processes. For these reasons, mass market brands often blend it with nylon or acrylic to reduce the price or they use 100% synthetic yarns or textiles that mimic wool.

Next-gen wool using sustainable and renewable inputs along with green chemistry will end the animal-cruelty associated with wool production and have the potential to decrease negative environmental impacts. Over time, next-gen prices should meet wool prices.

Wool Production Necessitates Slaughter

Wool is not a 'vegetarian' material as its production is not financially viable without also killing sheep and lambs for meat. This became clear to Nicole Rawling, MII's CEO, when she was invited a few years ago by an eminent U.S. apparel brand to visit a Californian wool farm which was an alleged paragon of sustainability and humaneness. When asked about slaughter, the farmers conceded that every year half of the lambs were killed for meat to maintain sufficient profits.

The farm also had a carbon-sequestering program, but the sequestration was not occurring through how the sheep interacted with the land. Instead, they were buying local compost to spread on their fields, which largely came from local dairy farms, meaning it further supported animal agriculture and its heavy environmental impacts.

Image credit: Zuzana Mit / We Animals Media

Image credit: KD New York
KD New York produces and sells dancewear garments from their proprietary Vegetable Cashmere™.

KEY TARGETS FOR CREATING WOOL ALTERNATIVES

While next-gen wool should (by definition) have a lower environmental impact without the animal-cruelty, these factors alone are not sufficient for success. Next-gen wool must also meet the performance attributes of wool and be cost-competitive.

Environmental Targets

The structure and composition of the fiber should lead to an environmentally preferable product compared with incumbents. Focus on these key areas:

- **Material inputs:** Inputs should be majority bio-based or recycled.
- **End of life:** The product should be recyclable, biodegradable, or capable of being responsibly disposed of at End-of-life.
- **Mitigate microfibers:** Shedding and release should be mitigated as much as possible through design and manufacturing.
- **Green chemistry:** Innovators should focus on non-toxic chemistry for dyes, additives, and treatments.
- **Impact reductions:** Innovators should target reductions in carbon emissions, water use, and land use among other environmental impact categories during production.

Tunability and Variety

It is critical for next-gen wool innovators to understand that to be successful they will need to offer a portfolio of yarns or finished textiles to brands. Animal-based and synthetic wools have a wide variety of colors, prints, patterns, textures, and lengths. While brands may understand that innovation takes time, innovators will need to be thinking about meeting those expectations long-term. For this industry to succeed, innovators will need a suite of yarns or textiles offering:

- **Colors:** Compatible non-toxic dyes are important.
- **Prints and patterns:** Make swatches or knit-downs showing your yarn's capabilities.
- **Textures:** Very smooth to very crimped or coarse yarns will offer a variety of looks.
- **Lengths:** Filament yarns are generally preferred and they can be made into staple fibers if desired.

Elicit Emotion

Wool products are known to appeal to human emotions and conjure up expectations – like warmth or protection. These are qualities that affect our emotional reactions:

- **Color:** Consider classic and seasonal colors including pastels, earth tones and brights.
- **Surface characteristics:** Target a smooth clean surface with low nap or fuzzy finish.
- **Drape:** This is important to apparel designers; look at the incumbent woolens to understand drape.
- **Aesthetics and haptics:** Never underestimate the importance of these two things as decisions to use your yarn will often begin with this.

Wear, Laundering, and Care

Anything that makes caring for a product—whether it is a blanket or apparel—easy and economical is a win for the consumer.

- **Machine washable:** The best option is to make your material machine washable.
- **Won't shrink:** It can be machine washed and dried without shrinking.
- **Smell:** Pleasant or no smell should come from the yarn or textile.
- **Won't pill:** After use or washing, your material should not pill.
- **Hypoallergenic:** Having hypoallergenic properties is valuable when considering wool products are frequently used or worn against the skin.

Next-Gen Wool (left) vs. Animal Wool (right)

Image credit: Osom Brand

Image credit: Silk City Fibers

Osom Brand's Osomtex (left) versus cashmere virgin wool blend (right).

Consider a Variety of Applications

As shown above, wool can be quite versatile across many different industries. The great variety of wool, wool blends, and acrylic in the marketplace capture many different end uses and markets. Innovators should explore these broad applications. As with all materials, some product categories may require regulations (i.e. flame retardancy) and should be researched.

- **Home goods:** Blankets, rugs, pillow shams, and bedding.
- **Furniture upholstery.**
- **Fashion and accessories:** There is broad use in apparel, outerwear, footwear and accessories for men, women and children in luxury to mass markets.
- **Outdoor market: Wool textiles and yarns used to dominate the outdoor apparel market before it shifted to nylon and acrylic products. This market is looking for environmentally preferable textiles.**

Brand and Manufacturing Partners

It is important to develop yarns that drop into the existing supply chain.

- **Brand feedback:** Working with a brand is crucial to get feedback on the performance, aesthetics, and handfeel of your materials in different applications.
- **Mill partner:** Work with a mill or textile manufacturer to ensure your yarn will work in the existing equipment. Manufacturing partners will be able to help you troubleshoot things such as tensile strength, crocking, or any other quality control problems.
- **Cut-and-sew factory:** Identify cut-and-sew factory partners early on to ensure your textile can successfully go through the existing cut/sew/trim process.

INNOVATORS: NEXT-GEN WOOL/ACRYLIC

14 innovators are working on next-gen wool/acrylic materials. These innovators are further split into fiber producers (10) and textile producers (4). Of the 15 innovators listed here, nearly half are still in R&D and some are working on multiple next-gen fiber innovations simultaneously. Those listed as "commercial" continue to iterate, seeking improved aesthetics and performance properties.

Next-Gen Wool/Acrylic Fiber Companies

Company	Material/ Fiber name(s)	Year Founded	HQ	Main Input	B2B or B2C	Stage	Website
ESG Brands	BANEX™	2022	USA	Plant-derived	B2B	R&D	www.theesgbrands.com
Flocus	Flocus™ Kapok	2014	NLD	Plant-derived	B2B	Commercial	www.flocus.pro
KD NY	Vegetable Cashmere™	2019	USA	Plant-derived	B2B & B2C	Commercial	www.kdnewyork.com
Kintra Fibers	Kintra	2018	USA	Plant-derived	B2B	R&D	www.kintrafibers.com
Kuura by Metsä Spring	Kuura™	2018	FIN	Plant-derived	B2B	R&D	www.kuura.io
OSOM	Osomtex®	2016	USA	Recycled Material	B2B & B2C	Commercial	www.osombrand.com
Spiber	Brewed Protein™	2007	JPN	Microbe-derived	B2B	Commercial	www.spiber.inc
Spinnova	N/A	2014	FIN	Plant-derived	B2B	Commercial	www.spinnova.com
Tandem Repeat	Squitex	2017	USA	Microbe-derived	B2B	R&D	www.tandemrepeat.com
Tencel by Lenzing	TENCEL™	1992	AUT	Plant-derived	B2B	Commercial	www.lenzing.com

Next-Gen Wool/Acrylic Textile Companies

Company	Material/ Fiber name(s)	Year Founded	HQ	Main Input	B2B or B2C	Stage	Website
Botanè	Botanical Cashmere	2020	ITA	Plant-derived	B2B	R&D	www.botanicalcash.com
Ecosimple	N/A	2010	BRA	Recycled Material	B2B	Commercial	www.ecosimple.com.br
Ettitude	PLNTwool™ and PLNT-cashmere™	2014	USA	Plant-derived	B2B & B2C	Commercial	www.ettitude.com
Faborg	WEGA-NOOL™	2015	IND	Plant-derived	B2B	Commercial	www.faborg.in

Image credit: ettitude
ettitude's throw made from their PLNTcashmere™.

SUB-CATEGORY #4 WITH LIMITED INNOVATION: DOWN

Image credit: Domenic Blair / Pixabay

WHAT MAKES DOWN SO SPECIAL?

Down refers to the soft, fluffy undercoating of feathers found on ducks and geese. Polyester fill is the synthetic, cheaper, and hypoallergenic replacement to down from animals. Both materials are commonly used as a filling material in home goods, apparel, footwear and outdoor markets.

Diversity of Applications

- **Bedding and pillows:** Down/polyfill is commonly used as a filling material for comforters, duvets, and pillows. Its natural insulation properties provide warmth without adding weight.
- **Apparel and jackets:** Down/polyfill jackets and coats are popular for their lightweight warmth. The insulating properties of down make it ideal for cold weather clothing.
- **Sleeping bags:** Down/polyfill sleeping bags are lightweight, compressible, and provide excellent insulation for outdoor enthusiasts.
- **Cushions, throws, and upholstery:** Down/polyfill is used as filling in cushions and throws, adding comfort and softness. Polyfill is also commonly used in quilts.
- **Feather beds:** Down/polyfill is used in feather beds and mattress toppers for extra cushioning and comfort. Pet beds often use polyfill for comfort and support.
- **Insulated boots and gloves:** Down/polyfill is used in the lining of winter boots and gloves.
- **Luxury bed linens:** Some high-end bed linens incorporate down for a luxurious feel.

Functionality

- **Insulation:** Down provides exceptional insulation due to its three-dimensional structure. The tiny, interlocking filaments trap air, creating pockets that retain warmth.
- **Lightweight:** Down is incredibly lightweight, making it comfortable to wear or sleep under without feeling bulky.
- **Breathability:** Its natural breathability allows moisture (such as sweat) to escape, keeping you warm without overheating.
- **Durability:** High-quality down can last for many years if properly cared for.
- **Fluffiness:** Down clusters fluff up easily, providing a luxurious feel.
- **Seasonless:** Down and polyfill come in a variety of weights (e.g. winter and summer weights) allowing for different levels of insulation.

Image credit: Switchback Travel

Image credit: Brooklinen

Structure

The structure of down with its fine fibers and air-trapping capabilities makes it a lightweight yet powerful insulator used in many products designed to keep us warm. To mimic the functionality of down, innovators will need to recognize the way the fibers come together. Small spaces between fibers trap air to act as insulators. Many brands will mix feathers with down. Feathers, because they are stiffer, offer more structure to whatever they are filling. A higher down-to-feathers ratio equals a higher puff factor and more warmth.

The structure of down is quite unique:

- **Types of down:** There are three main types of down—natal down, body down, and powder down. Natal down covers most birds at some point in their early development. Body down lies underneath the outer contour feathers on a bird's body and helps to insulate against heat loss. Powder down, or pulviplumes, is a special type of down that occurs in a few groups of birds and contributes to the buoyancy of waterbirds.

- **Down clusters:** These are composed of thousands of tiny fibers that intersect in various directions, creating air pockets. These pockets are what allow down to trap and retain body heat, making it an excellent insulator.

- **Loft (fluffiness):** As birds mature, their plumage tends to become larger, which results in increased loft and a higher fill power rating. Fill power is a measure of the loft or fluffiness of the down and relates directly to its insulating value.

Image credit: Allied Feather & Down
This image shows a range of down clusters typically used in outdoor apparel, from the largest cluster being nearly the size of a quarter, down to the smallest dime-sized cluster.

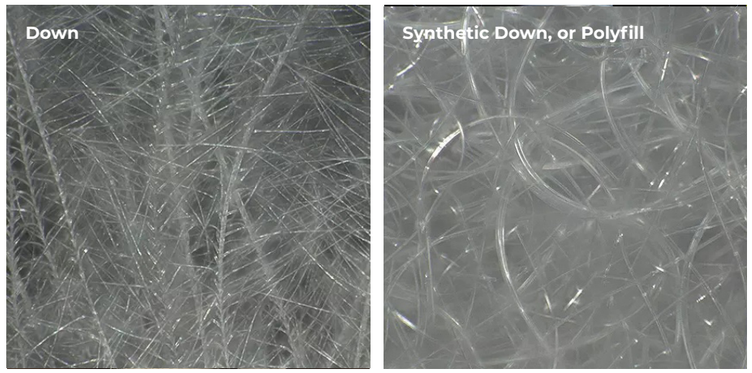


Image credits: Columbia Sportswear Company

Polyfill versus Down

Polyfill offers several advantages and a few disadvantages when compared to down fill. Innovators should consider the practical advantages of polyfill and try to meet or exceed these qualities.

Advantages:

- **Hypoallergenic:** Down can trigger allergies for some people.

- **Affordability**: Polyfill is generally more affordable than natural down.

- **Easy care:** Polyfill can often be machine washed and dried (depending on the shell fabric), while natural down requires more delicate care, usually dry cleaning.

- **Consistency:** Polyfill can be manufactured to have consistent loft and fill power, whereas natural down can vary in quality.

- **Resilience:** Polyfill retains its shape and fluffiness over time.

Disadvantages:

- **Less breathable:** Not as breathable as down.

- **Heavier:** Slightly heavier than down.

- **Environmental impact:** Polyester production has significant environmental implications.

Image credit: VIER PFOTEN International

HOW CAN DOWN BE IMPROVED?

Animal Welfare Concerns

- 3.4 billion ducks and geese are slaughtered every year in the production of down and feathers, a conservative estimate for their use in fashion only.[1]
- The feathers and down in our wardrobe and home goods come from birds that have been slaughtered for meat or repeatedly live-plucked.
- Live plucking is a common practice on factory farms in the major down-producing countries, including China (which produces about 80% of the world's down and feathers), Poland and Hungary.[2]
- Live plucking has been determined to be so inhumane that it has been outlawed in the U.S. and several European countries; however, these laws are not enforced.
- Ducks and geese are aquatic and must spend a large portion of their lives on the water to be healthy. Their legs have not evolved to support their weight for extended periods, yet they are confined in factory farms on land to produce down.

Down's Environmental Impact

- **Water pollution:** Large-scale duck and geese farming operations may generate significant amounts of waste, including feces and excess feed. If not properly managed, this waste can leach nutrients and pollutants into waterways, leading to water pollution and eutrophication.
- **Air pollution:** All of animal agriculture releases ammonia, methane, and other gasses into the air. This can impact local air quality and contribute to climate change.
- **Water use:** Duck and geese farming operations require significant amounts of water for drinking, cleaning, and processing.
- **Habitat destruction:** Converting land for duck and geese farming may involve clearing natural habitats leading to habitat destruction and loss of biodiversity.
- **Zoonotic diseases:** Farming animals on a large scale can lead to disease and death for the animals and possibly spread diseases to humans or other animals. Ducks and geese are aquatic birds and, therefore, increase the risk of Avian Flu.

Polyfill's Environmental Impact

- **Energy consumption and pollution**: The production of polyester involves the use of large amounts of energy and water, as well as the release of harmful chemicals and greenhouse gasses.
- **Resource use:** Polyester is made from oil, a non-renewable resource, and a significant source of pollution.
- **Non-biodegradable:** Polyester is not biodegradable and can take hundreds of years to decompose. This contributes to the growing problem of plastic pollution in our oceans and landfills.
- **Microplastics:** The production and laundry processes release tiny fibers known as microplastics, which can be harmful to all animals, including humans.(See our Impact of Synthetic Materials on Animals report for more.)[3]

Down and Polyfill Performance and Care

- **Consistency:** Down feathers can be inconsistent in their lack of uniformity. Down feathers can vary greatly in quality depending on the species of bird, their age, and the environment in which they live. This variability can affect the insulating properties of the down, making it difficult to maintain consistent performance across products.
- **Laundering:** Down fill requires special cleaning procedures which often involve using a gentle, down-specific detergent and avoiding fabric softeners, which can coat the down and reduce its ability to loft.
- **Water-resistance:** Down loses its insulating properties when wet. The only way to avoid this issue is to use a water-resistant shell or treating the down with a durable water repellent (DWR) but both practices require potentially toxic chemicals and are not environmentally friendly.
- **Fluffiness:** Unless stored properly, down can lose its loft and fluffiness and may not return to its original shape through fluffing.
- **Heat buildup:** Polyester restricts airflow, which can cause heat buildup in products made from polyfill.
- **Moisture absorbency:** Polyester has low moisture absorbency. Sweat and moisture may linger on the skin.

Image Credit: Ponda

KEY TARGETS FOR CREATING DOWN ALTERNATIVES

Environmental Targets

Major industries like apparel, accessories, home goods, childrens' wear, and footwear are looking for safe, environmentally preferable products.

- **Material inputs:** The majority of inputs should be bio-based or recycled.
- **End-of-life:** The material should be recyclable, biodegradable, or capable of being responsibly disposed of at end-of-life.
- **Mitigate microfibers:** Shedding should be mitigated as much as possible through design and manufacturing.
- **Green chemistry:** Innovators should focus on non-toxic chemistry for dyes, additives, and treatments.
- **Impact reductions:** Innovators should target reductions in carbon emissions, water use, land use and other environmental impact categories during production.

Tunability and Variety

To meet brands' needs, innovators should offer the following:

- **Weights:** Various weights will be needed for products ranging from pillows to outerwear and footwear.
- **Thicknesses:** Different products will require different thicknesses of fill.
- **Densities:** Different industries will require different densities. The auto industry will want something very different from an apparel maker.

Fill/Interior

Fill, by definition, is filling an area between two layers of fabric. Consider the end product to understand how your material will need to perform when used by a consumer as well as when it is going through the manufacturing process. See “Brand and Manufacturing Partners” to the right.

Wear, Laundering, and Care

- **Easy care:** Machine washability and machine or line dry-ability should be the goal.
- **Odor free:** Pleasant or no smell should come from the textile.
- **Hypoallergenic:** Although fill will generally be contained inside of another fabric, it is always a good idea to be skin safe.
- **End-of-life:** It should be recyclable or biodegradable.

Next-Gen Down (left) vs. Down from Birds (right)

Image Credit: Ponda

Image credit: Zhane Luk / Shutterstock

Consider a Variety of Applications

- **Home products:** Pillows, comforters, cushions.
- **Outerwear:** Skiwear, outdoor apparel, fashion.
- **Footwear:** Sneakers, boots.
- **Accessories:** Mittens, scarves, hats.
- **Children’s products:** Stuffed animals, bedding, apparel, footwear.
- **Auto industry:** Interiors.

Brand and Manufacturing Partners

Working with a manufacturer directly or through a brand’s supply partner will take away the guesswork of knowing if your material is viable.

- **Early feedback:** A manufacturing partner will be able to address any problems with your material while you are still in development.
- **Can it be stitched:** Will the needle go through cleanly when sandwiched between layers of fabric?
- **Accelerated development:** Working with a manufacturing partner familiar with ‘filled’ products early on will hasten your road to scaling and brand adoption.

INNOVATORS: NEXT-GEN DOWN

The following are companies innovating down. We are dividing the start-up innovators from the established large corporations with wide product lines, but which continue to develop more sustainable next-gen materials. We have also included a brand innovating their own materials.

Next-Gen Down/Poly Producers, Start-ups

Company	Material/ Fiber name(s)	Year Founded	HQ	Main Input	B2B or B2C	Stage	Website
Eco Supreme	N/A	2008	USA	Microbe-derived	B2B	Commercial	www.ecosupremeus.com
Flocus Kapok	N/A	2014	NLD	Plant-derived	B2B	Commercial	www.flocus.pro
Monark	N/A	2013	CAN	Plant-derived	B2B	R&D	www.coopmonark.com
Mycocycle	MicoFILL©	2018	USA	Mycelium	B2B	R&D	www.mycocycle.com
Pangaia	FLWRDWN™, FLWRFILL™	2018	GBR	Plant-derived	B2B & B2C	Commercial	www.pangaia.com
Pangaia Grado Zero	BioGreen Padding, Kapok, nVeg Padding	2001	ITA	Plant-derived	B2B	Commercial	www.lifematerials.eu
Ponda	BioPuff®	2020	GBR	Plant-derived	B2B	R&D	www.ponda.bio
Vegeto	Milkweed	2018	CAN	Plant-derived	B2B	R&D	www.vegetotextiles.com

Image credit: Cyril Ruoso / Minden

Next-Gen Down/Poly Producers, Established Corporations

Company	Material/ Fiber name(s)	Year Founded	HQ	Main Input	B2B or B2C	Stage	Website
3M Thinsulate	Thinsulate™ Featherless Insulation	1902	USA	Recycled Material	B2B	Commercial	www.3m.com
Polartec	Power Fill™	1906	USA	Recycled Material	B2B	Commercial	www.polartec.com
PrimaLoft	PrimaLoft® Bio™, PrimaLoft® ThermoPlume®	1983	USA	Recycled Material	B2B	Commercial	www.primaloft.com
Lenzing	TENCEL™	1938/2004	AUT	Plant-derived	B2B	Commercial	www.lenzing.com
Thermolite	THERMOLITE® EcoMade T-DOWN	1958	USA	Recycled Material	B2B	Commercial	www.lycra.com
Thermore	Ecodown®	1972	NLD	Recycled Material	B2B	Commercial	www.thermore.com

Brands with Internal Material Innovation

Company	Material/ Fiber name(s)	Year Founded	HQ	Main Input	B2B or B2C	Stage	Website
Save the Duck	PLUMTECH®	2012	ITA	Recycled Material	B2C	Commercial	www.savetheduck.com

MATERIAL INNOVATION INITIATIVE

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Credits:

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About MII

The Material Innovation Initiative is a nonprofit think tank that accelerates the development of high-performance, animal-free, and environmentally preferred materials with a focus on replacing silk, wool, down, fur, and leather and their synthetic alternatives. We advance the next-gen materials revolution by connecting science and big ideas. We focus on research, knowledge-sharing, and fostering connections to fast- track the development of environmentally preferable and animal-free materials.

We work to cultivate a global market for next-gen materials across the fashion, automotive, and home goods industries. We work for materials that can do more while requiring less of the planet, animals, and people involved at every stage. We imagine a circular future where the default choice for your sweater, sneaker, or seat is humane and sustainable. A future where animals are allowed to live free and thrive, the planet is saved from pollution and degradation, and workers are treated fairly and with respect.

Please consider a tax-deductible gift, or join us as a monthly-sustainer, and thank you.

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NOTES

Definitions

1. In this report, we modify the European Committee for Standardization's definition of "bio-based products" so as not to include any animal-derived products.
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Image credit: Élodie Chapuis
Peet Dullaert's couture gown made from Lenzing's TENCEL™ Luxe.

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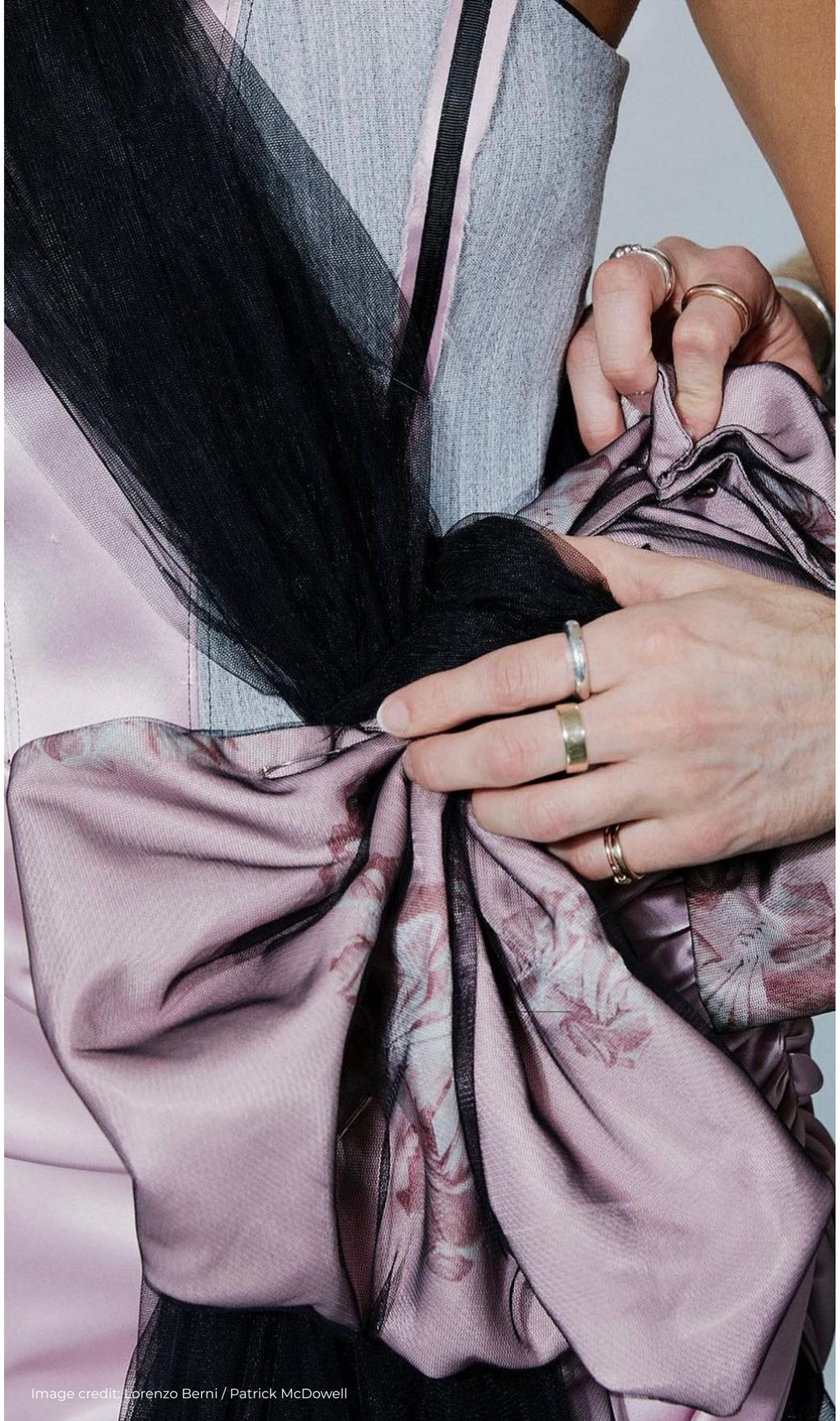

Image credit: Lorenzo Berni / Patrick McDowell

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