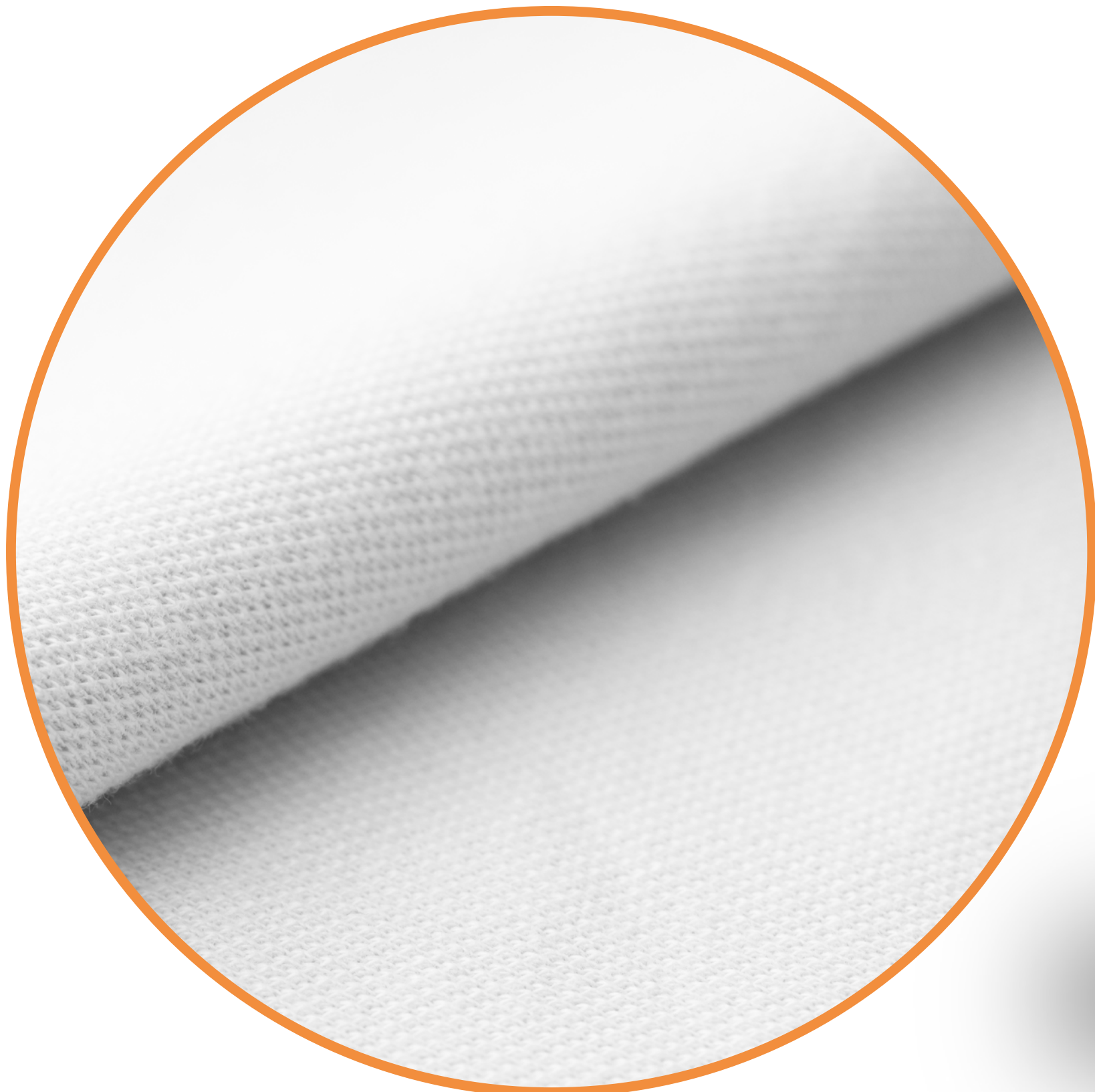


01 Advanced Fibres

Engineering cellulose for next-generation textile applications

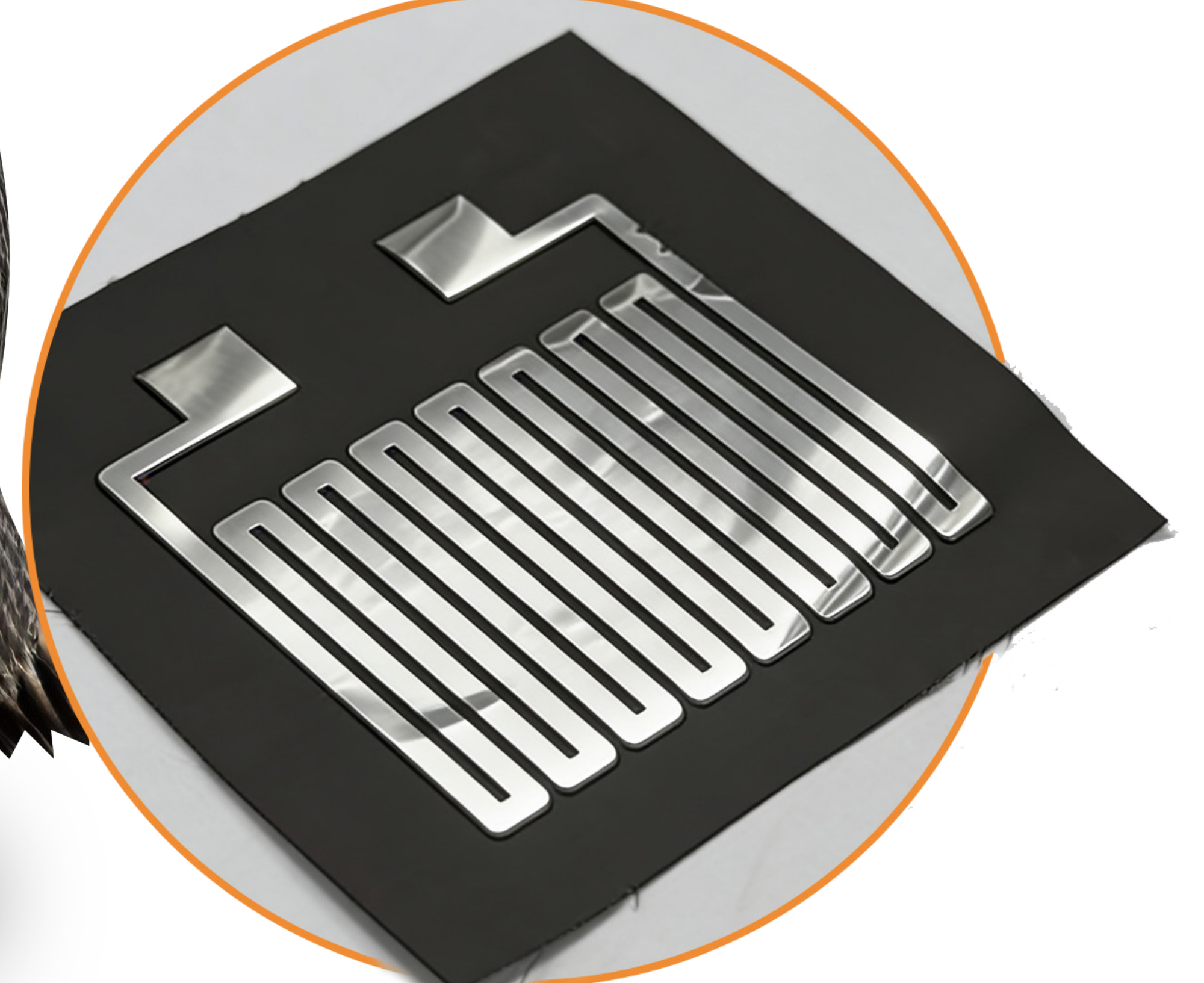
PENGUIN starts at the fibre level, where advanced cellulose fibres are being tailored to combine sustainability with the performance requirements of technical outdoor textiles. Activities focus on improving hydrophobicity, wash durability, fibre morphology, and industrial processability while progressively moving from laboratory-scale treatments towards larger-scale manufacturing routes. Recent developments include advanced Biocelsol and SPINNOVA fibres, together with the upscaling of fibre processing and finishing approaches. Larger-scale fibre finishing routes are already under development, while hydrophobization strategies improved fibre water repellency, increasing contact angle values from approximately 71° to 92° for SPINNOVA fibres and from 80° to 115° for Biocelsol fibres.



02 Insulation Materials

Redesigning insulation through structure

Rather than directly replacing polyester or down insulation materials, PENGUIN is redesigning insulation systems around the specific behaviour of cellulose-based materials to maximise thermal performance, comfort, and lightweight structures. Multiple routes including foam forming and airlaid technologies, and loose-fill fibreball systems are being explored by optimizing, for example, fiber blends, porosity, and bonding of the structures. The latest developments already demonstrated highly promising results, reaching CLO values up to 3.9 with foam-formed structures and 4.1 with air-laid structures, and fill power values around 400 cuin/30 g with loose-fill materials, which are comparable to conventional references.



03 Functional Textile Architectures

Turning materials into textile systems

As material maturity increases, PENGUIN is increasingly focusing on integrating fibres and insulation materials into realistic textile structures representative of future garment applications. Activities include multilayer assemblies i.e. sandwich structures composed of insulation materials and fabrics developed in the project, as well as their testing. Recent developments successfully demonstrated textile structures incorporating 30% SPINNOVA fibres, together with high abrasion resistance even after repeated washing conditions. These activities are progressively helping bridge the gap between material development and realistic textile implementation scenarios.

04 Smart Functionalities & Wearable Integration

Adding functionality without compromising comfort

PENGUIN is also exploring how smart functionalities can be integrated into wearable textile systems while preserving comfort and future circularity strategies. Current developments focus on smart functionalities, wearable integration approaches, circular design strategies and garment-level validation activities. Recent activities demonstrated the feasibility of integrating smart functionalities into wearable textile systems, while wearable integration activities continue progressing towards garment-level validation and future comfort assessment under representative outdoor conditions.

05 Bio-inspired Chemistries

Building performance directly into the material

Nature-inspired chemistry plays a central role in PENGUIN by improving material functionality through more sustainable approaches. Rather than relying solely on conventional synthetic additives, the project is developing bio-based binders and functional treatments designed to enhance wet strength, hydrophobicity, processability, and structural cohesion of cellulose-based systems. Recent developments have also demonstrated promising durability, with hydrophobic modifications maintaining performance after repeated washing cycles. These approaches are progressively enabling functionality to be engineered directly into the material itself while remaining aligned with sustainability objectives.

06 Circularity by Design

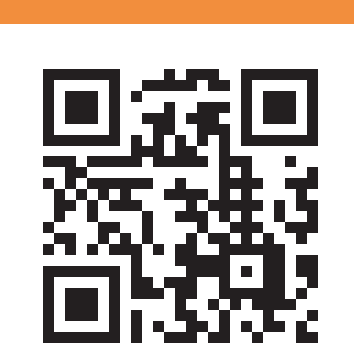
Considering end-of-life from the beginning

Circularity considerations are integrated from the early stages of material and system development rather than being addressed only at the end of the process. Material selection, component compatibility, and system architectures are increasingly being designed to facilitate future separation, reuse, and recycling pathways. Particular attention is also being given to reuse, repair, component recovery and recycling strategies, together with design approaches that support future circular textile value chains.

07 Designed for Real Outdoor Use

Moving beyond laboratory conditions

Ultimately, materials need to perform under realistic use conditions. PENGUIN therefore increasingly evaluates its technologies under scenarios representative of future outdoor environments, including laundering campaigns, thermal comfort assessments, structural durability testing, and garment-level integration activities. Recent washing campaigns already included repeated cycles at 30 °C, while future demonstrators are targeting promising thermal comfort performance under representative conditions.



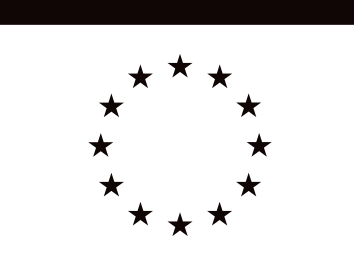
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