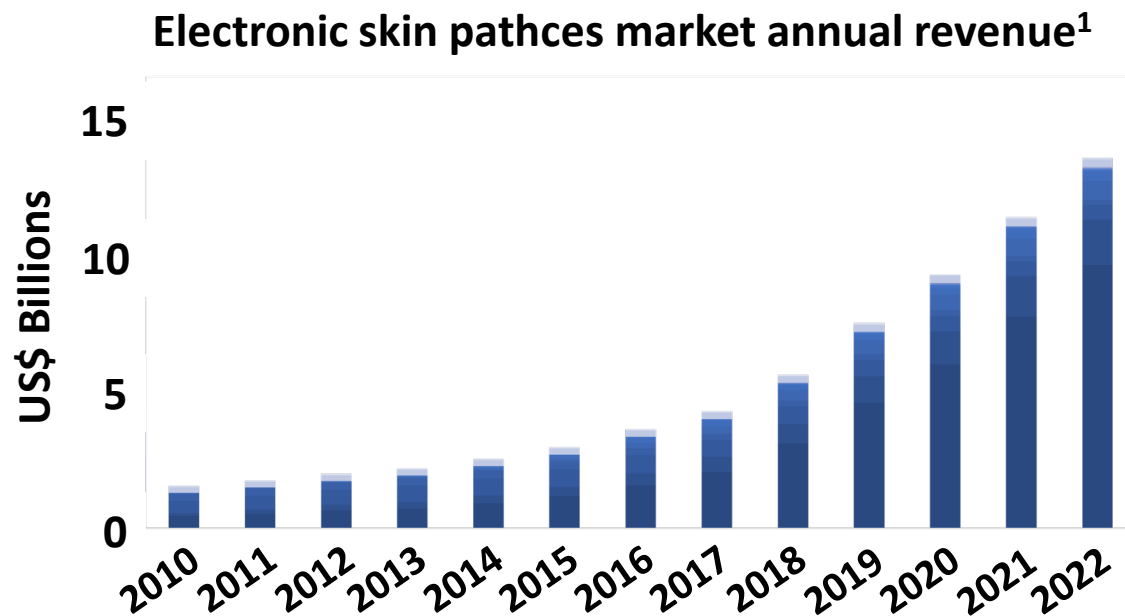


Recyclable nanocellulose composite substrates for flexible electronics

Tia Lohtander-Piispa, Akio Yamamoto, Elina Jansson, Hanna-Leena Alakomi, Minna Vikman, Petri Widsten, Alexey Khakalo, Mohammad Behfar, Hannes Orelma, Katariina Torvinen, Vinay Kumar, Tekla Tammelin



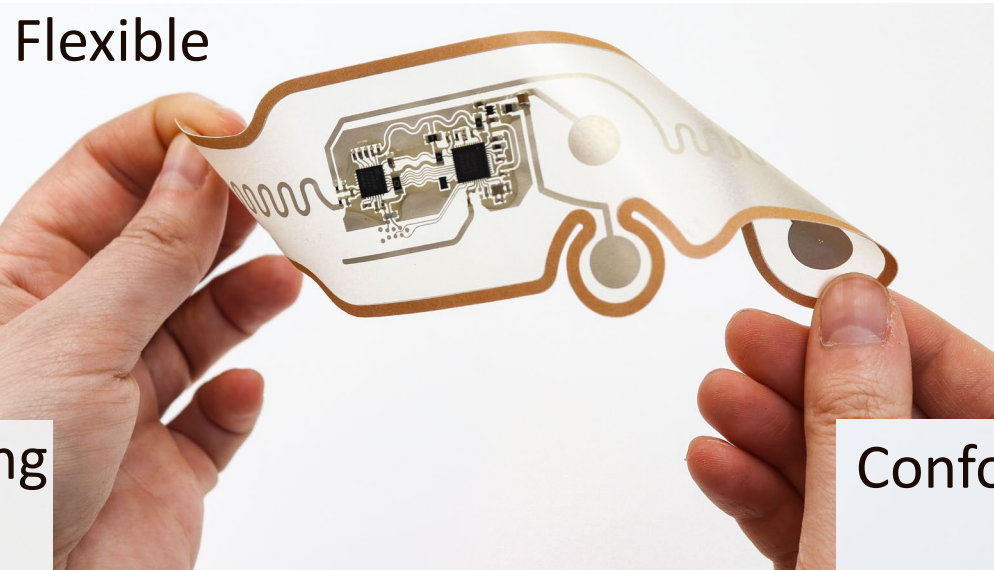
Flexible electronics



- Electronic skin patch market forecast to grow to over US\$27B by 2033¹
- Plastics as state-of-the-art substrates
 - Single-use patches
- EU: Sustainable Products Initiative

¹<https://www.idtechex.com/en/research-report/electronic-skin-patches-2023-2033/900>

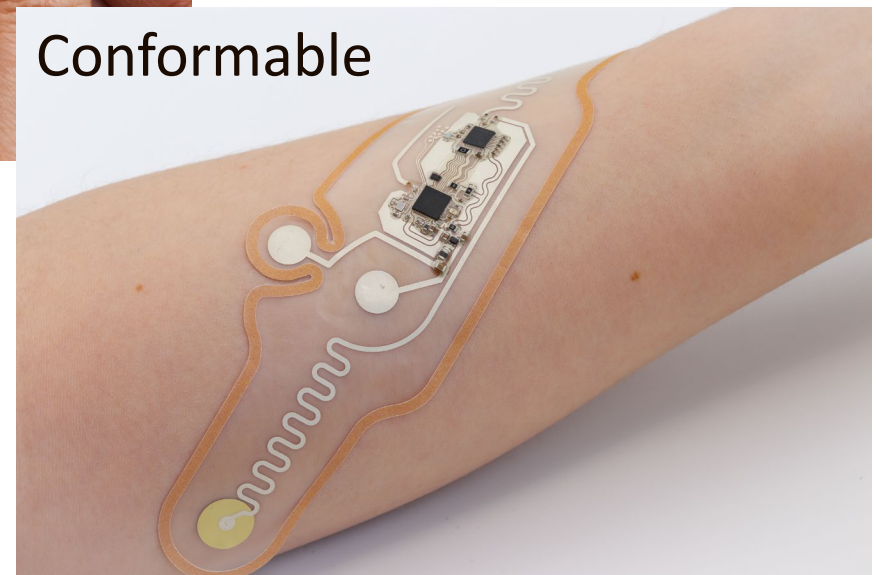
First proof-of-concept CNF substrate



Compatible for printing



Conformable



Research objectives

- Nanocellulose films tear easily
 - How to prevent tear formation and tear propagation?

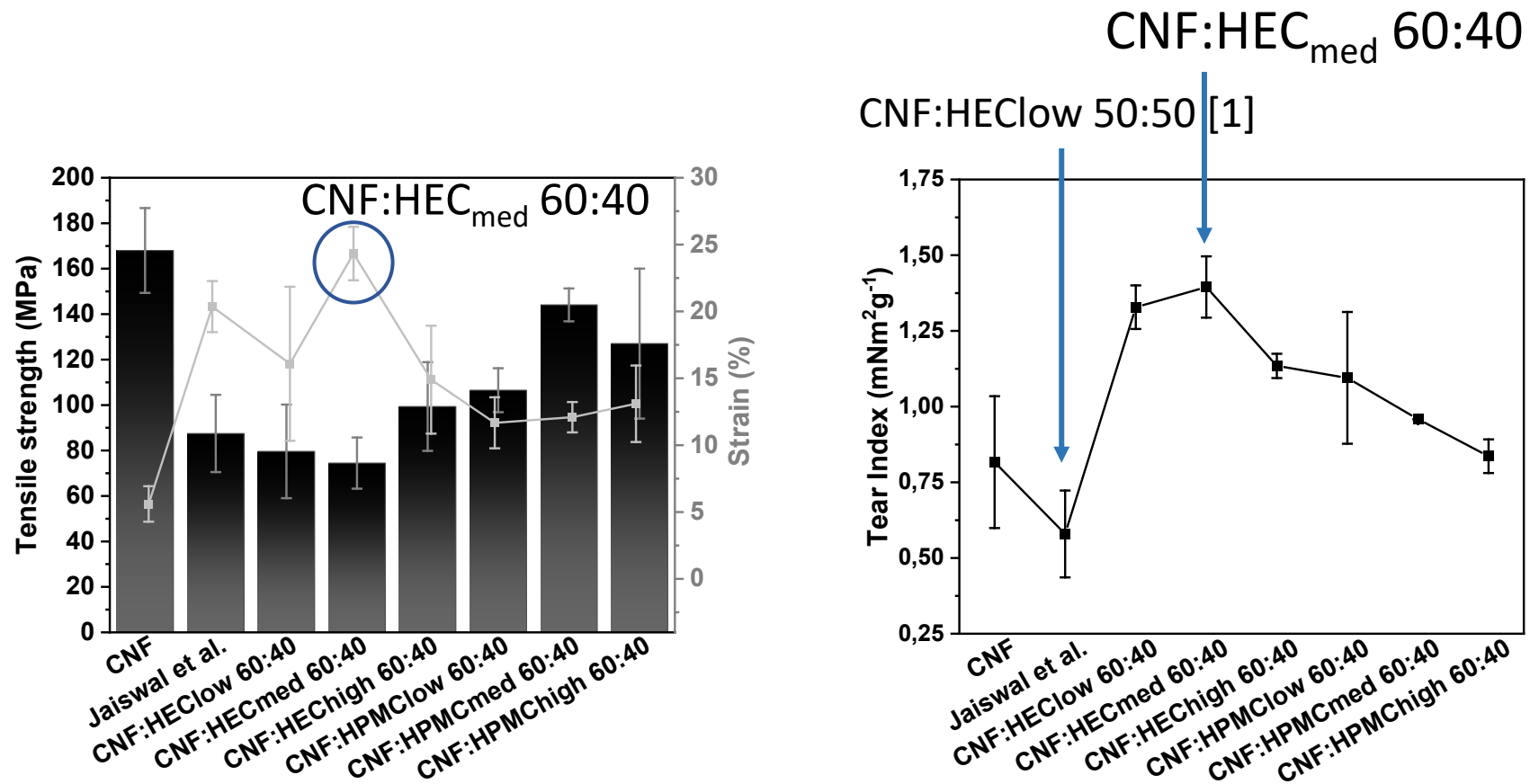
- Plasticization of films
 - Crystallization of sorbitol and alternatives

- Valuable metals on single-use patch
 - Bio-based electrodes from carbon

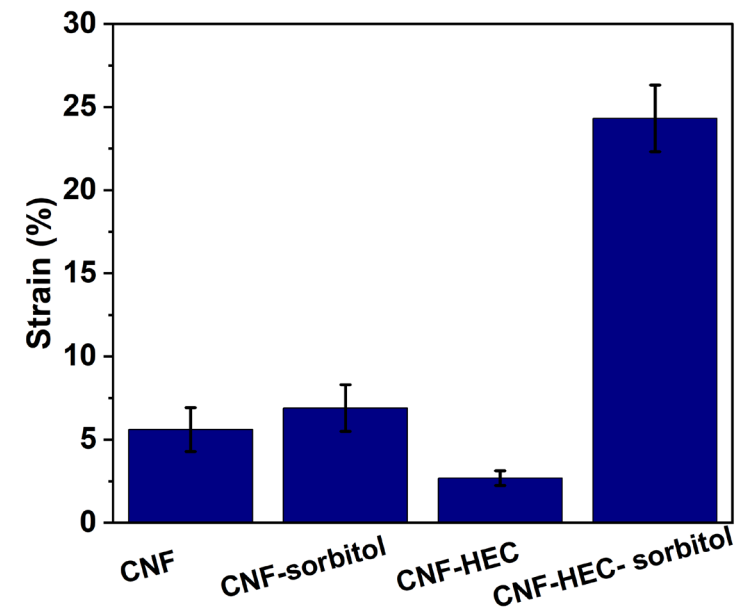
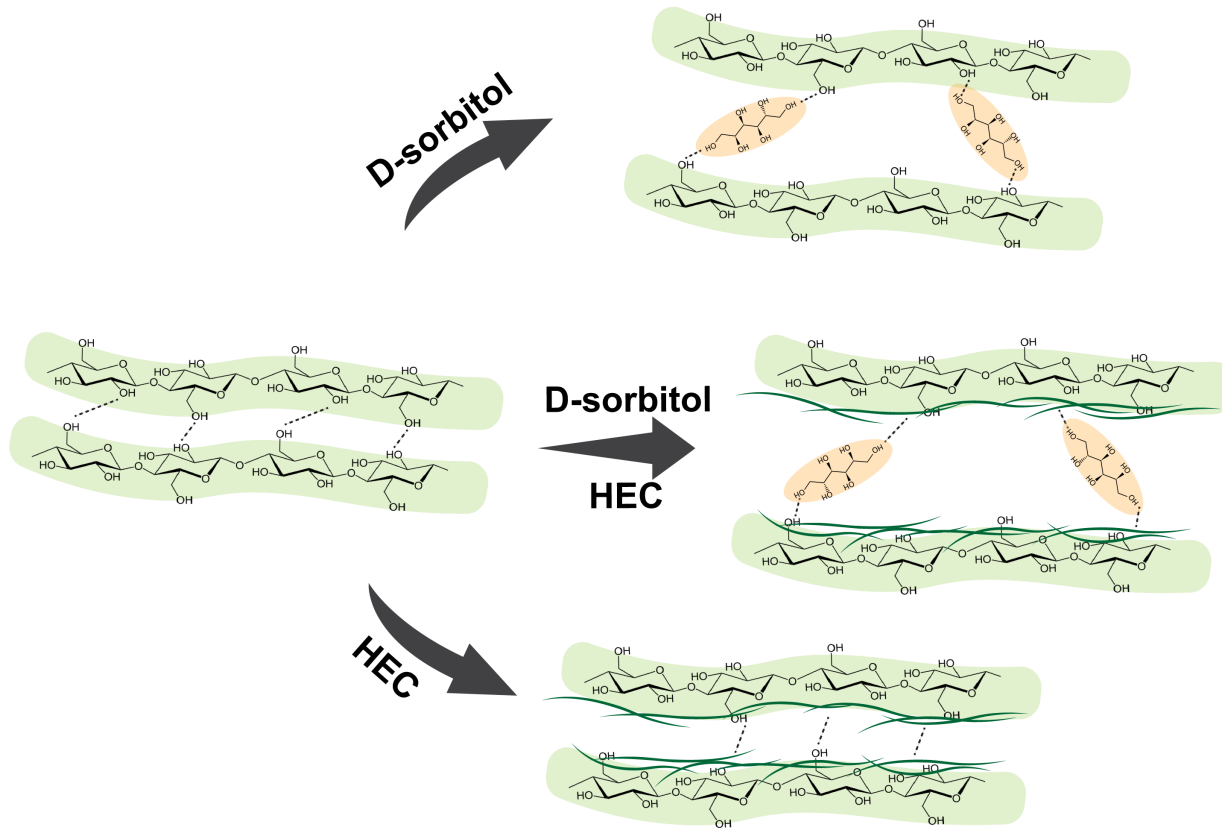
- End-of-life management
 - Biodegradability
 - Recycling

Improved tear resistance

Goal: strain > 20%, Tensile strength > 50 MPa, Tear Index > 0.81 mNm²g⁻¹ (CNF:HEC_{low} 50:50 [1])



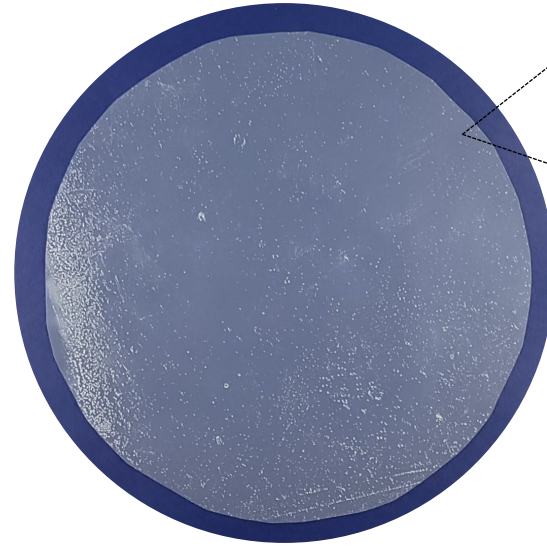
Dual plasticization with HEC and sorbitol



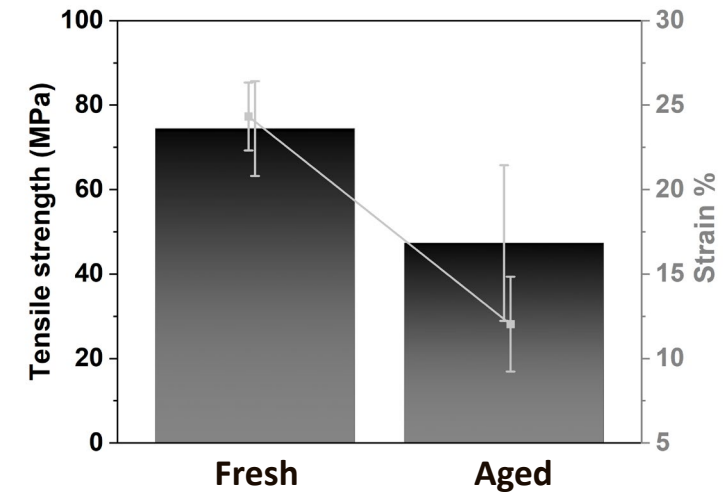
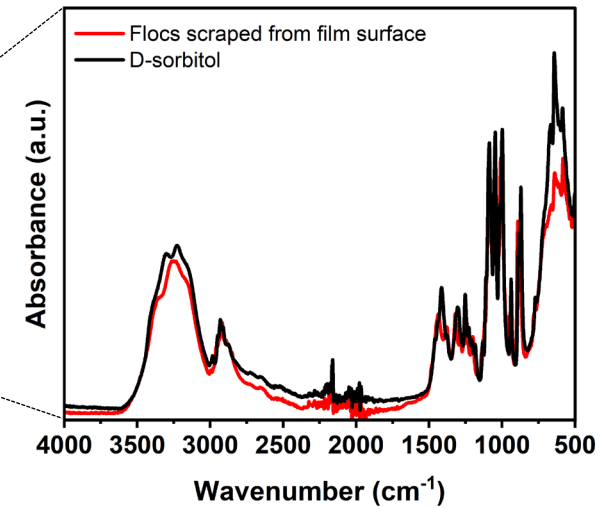
Limited lifetime – sorbitol recrystallization



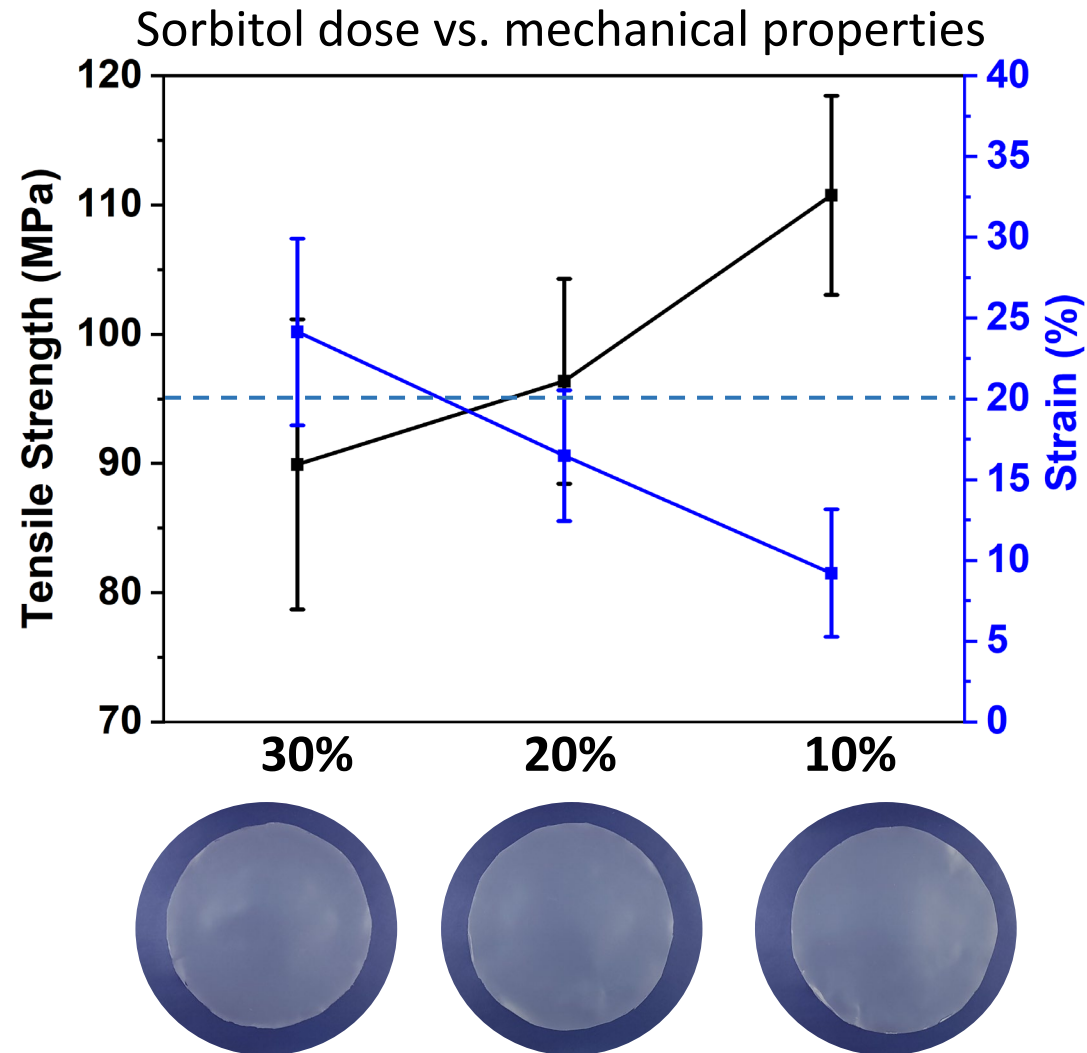
Fresh film



Aged film

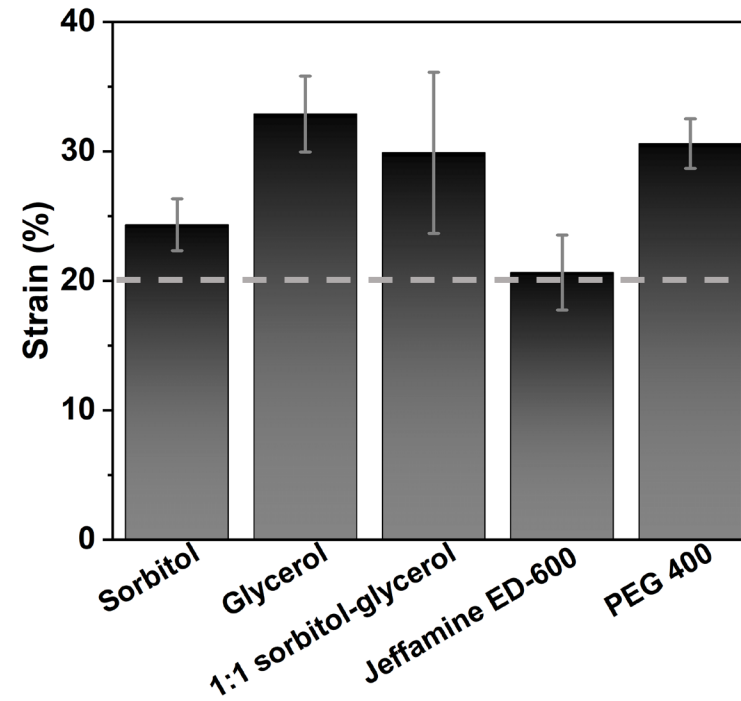
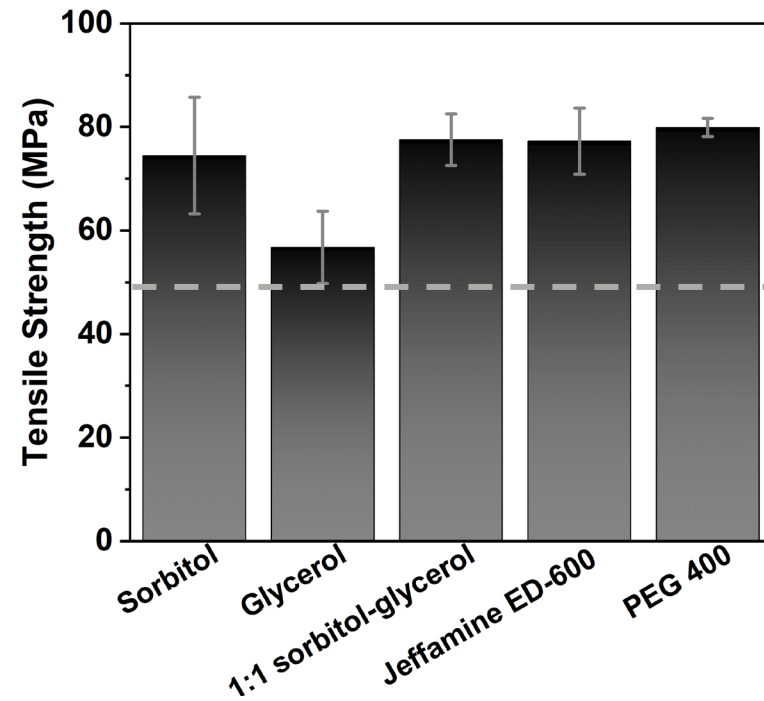


Mitigation action: sorbitol dose



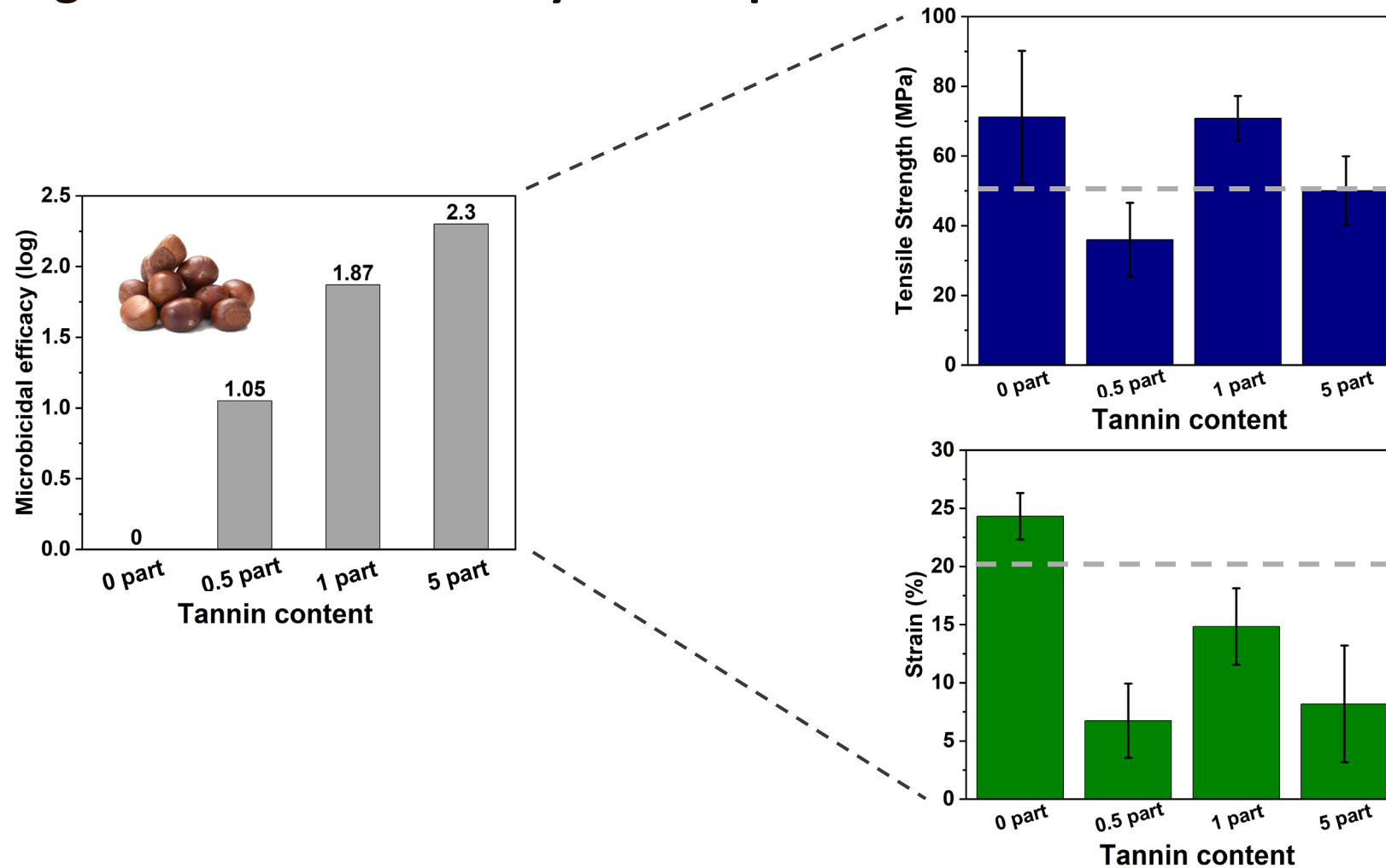
Alternative plasticizers

Goal: strain > 20%, Tensile strength > 50 MPa, Tear Index > 0.81 mNm²g⁻¹ (CNF:HEC_{low} 50:50 [1])



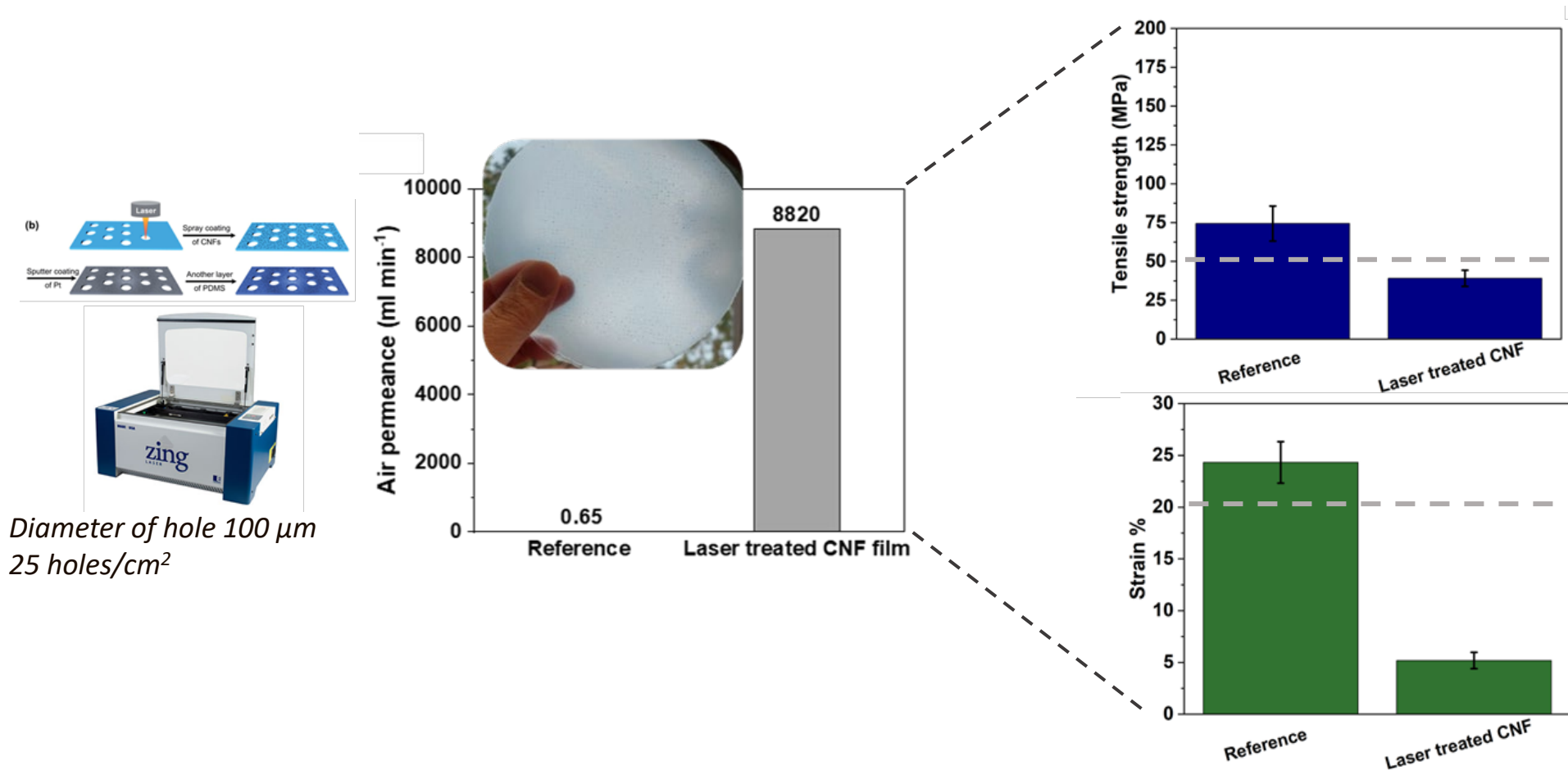
Functionalization of the composite film

Integrating antimicrobial activity to skin patch

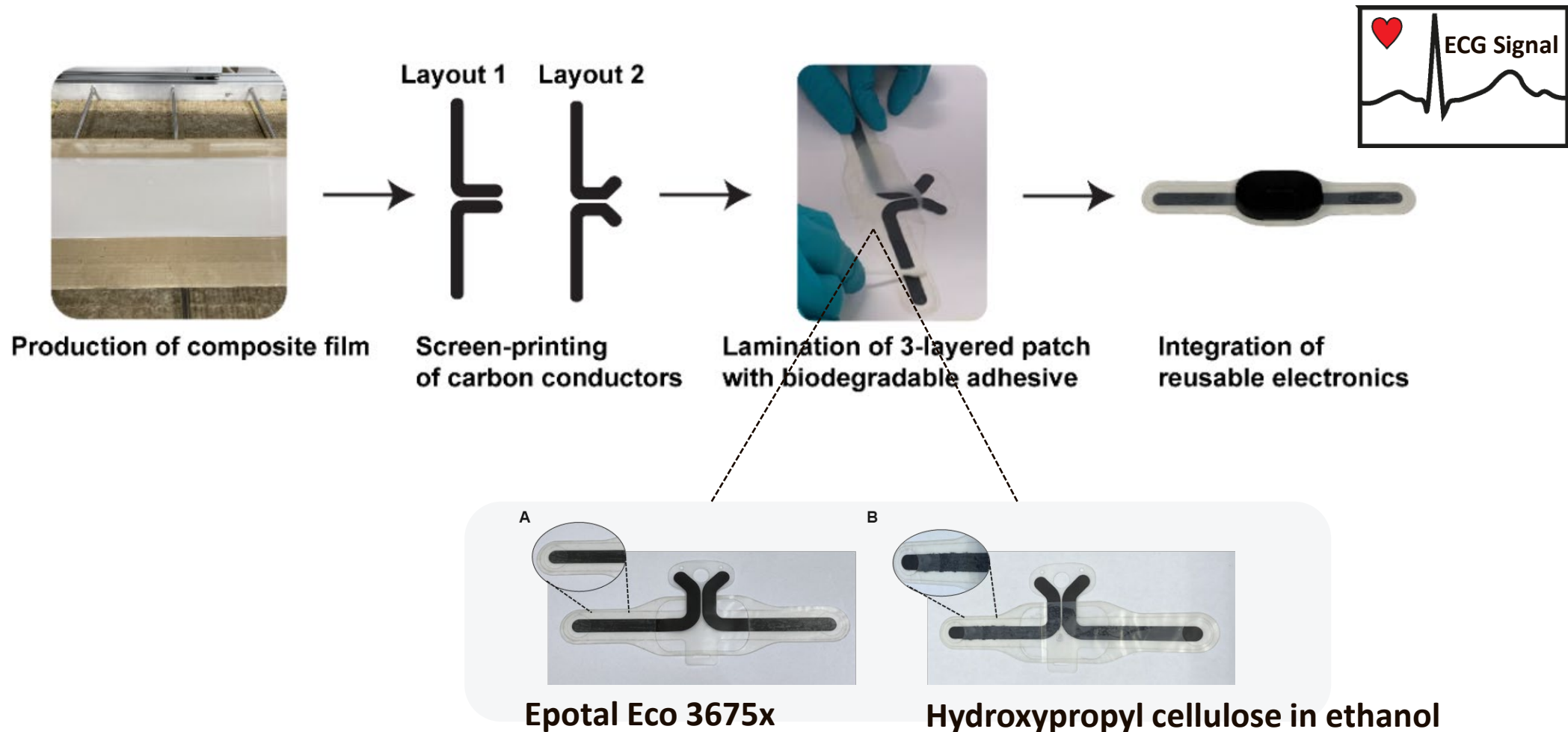


Functionalization of the composite film

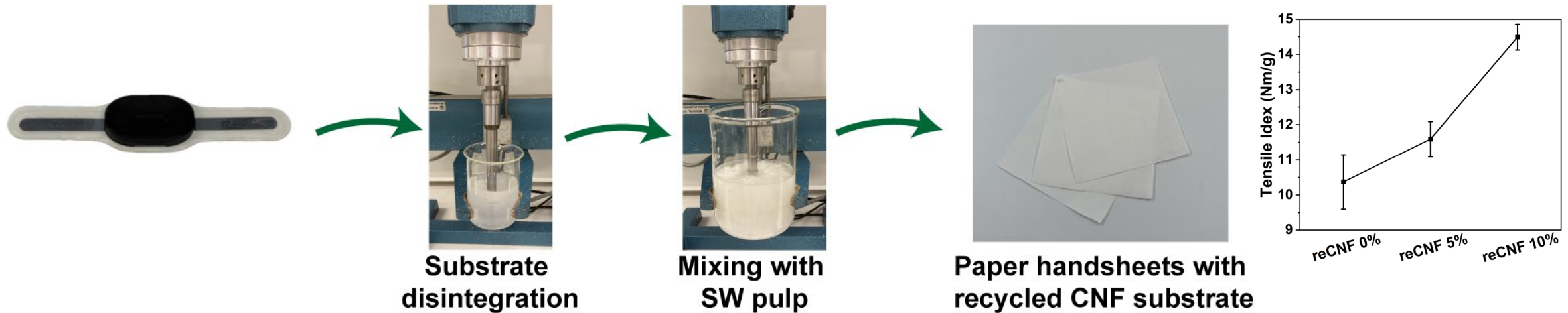
Improving breathability of skin patch



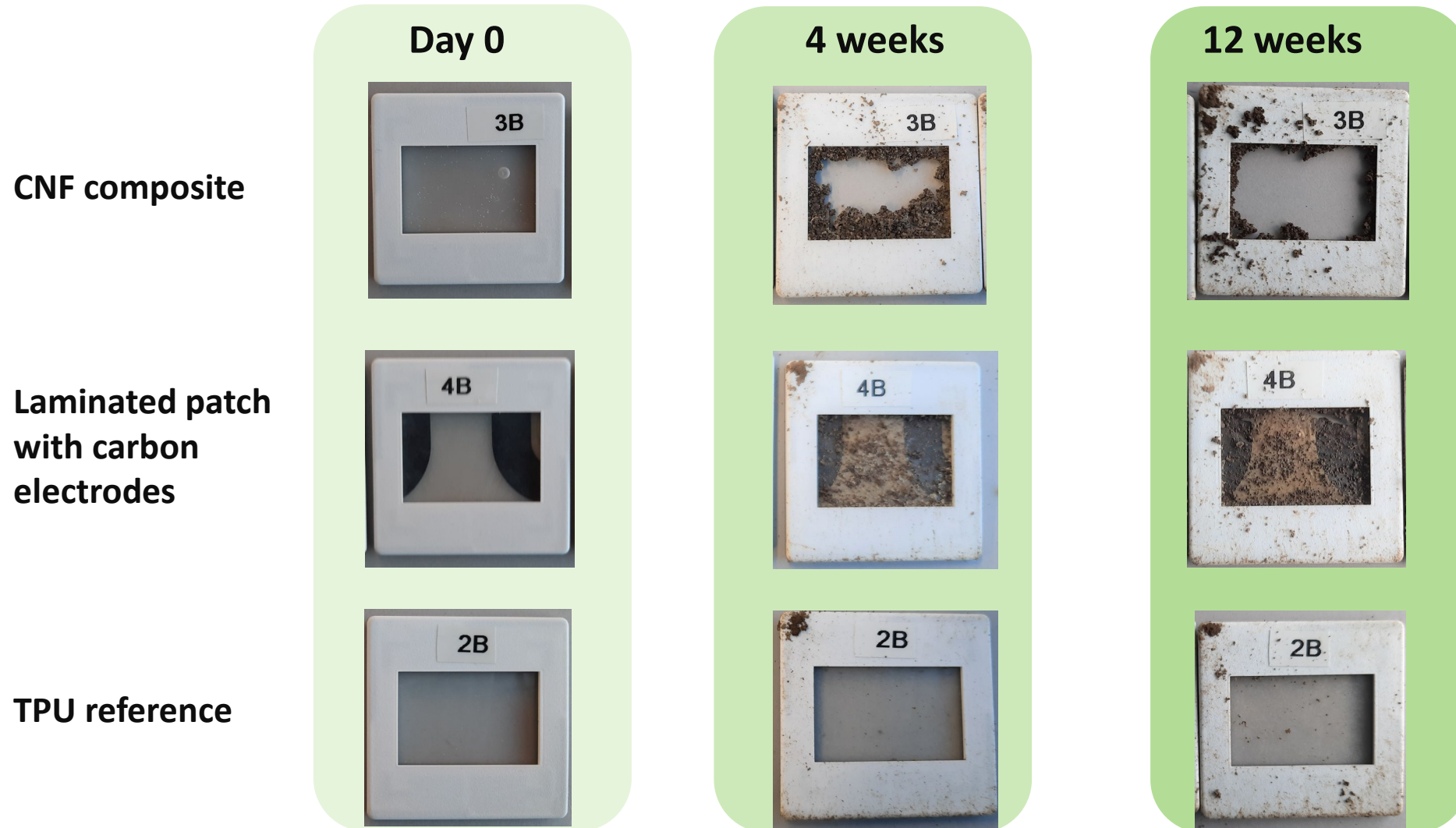
Demonstration – substrate for recyclable flexible electronics



End-of-life: Recycling into paper additive



End-of-life: Biodegradability



Conclusions

- A combination of flexible polymer and small molecules is needed to plasticize CNF
- However, sorbitol crystallizes in a more plasticized system
- High-footprint silver in electrodes can be replaced with carbon
- The substrate is recyclable and biodegradable, but the lamination reduces biodegradability



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