Supportive Information

Transforming Textile Waste into Nanocellulose for a Circular Future.

Thenapakiam Sathasivam[a], Sigit Sugiarto[a], Michelle Pek Yin Yew [b], Xin Yi Oh[a], Siew Yin Chan[b], Benjamin Qi Yu Chan[b], Mao Jie Tim [c], Dan Kai[a,b,d]

[a] Institute of Sustainability for Chemicals, Energy and Environment (ISCE2), The Agency for Science, Technology and Research (A*STAR), 2 Fusionopolis Way, Innovis, #08-03, Singapore, 138634 Singapore

[b] Institute of Materials Research and Engineering (IMRE), The Agency for Science, Technology and Research (A*STAR), 2 Fusionopolis Way, Innovis, #08-03, Singapore, 138634 Singapore

[c] Chemical & Biomolecular Engineering, College of Design and Engineering, National University of Singapore, 4 Engineering Drive 4, Singapore 117585, Singapore

[d] School of Chemistry, Chemical Engineering and Biotechnology, Nanyang Technological University, 21 Nanyang Link, Singapore 637371, Singapore

* Corresponding Author: kaid@imre.a-star.edu.sg

S1. Pre-treatment of cotton-based textile

S1.1 Sorting cotton-based textile waste by fiber and colour

Textile waste recycling begins with a crucial step: sorting. However, this becomes challenging due to the mixing of textile components, leading to difficulties in separating and breaking down fibers into their chemical building blocks and affecting nanocellulose quality. Textile blending occurs at different stages, complicating sorting processes that currently rely on labor-intensive manual methods, lacking precision and efficiency. To address this, researchers are exploring effective ways, such as using infrared (IRS) and near-infrared (NIRS) spectroscopic method, to differentiate textile waste based on fiber type and color[1]. Riba et al. have introduced a rapid Fourier-transform infrared-based mathematical method for direct and non-invasive sorting and classification of fabric fibers, offering potential solutions to the challenges in recycling waste cotton for nanocellulose production[2]. The results of automated processes showed a 100% accuracy rate in classifying unidentified fiber samples without prior analytical treatment of textile samples, although accuracy could be affected by dirt, moisture, or contaminants. Cura et al. explored NIRS for textile waste categorization, but limitations were noted, such as sample thickness affecting recognition as NIRS only evaluates surface properties[3] (**Figure S1A**). Rodgers et al. demonstrated NIRS's practicality in measuring cotton content in blends despite differences in matrices like dyes, finishes, and fabric construction, mitigating variations through normalization treatments[4]. Additionally, Zhou et al. utilized digital cameras and color recognition models for waste textile color identification, hinting at potential for advanced sorting systems integrating NIRS with color recognition methods [5].

One creative solution to sorting challenges is the use of Radio Frequency Identification (RFID) tags (**Figure S1B**), which can be integrated into fabric hems during garment production, allowing sorting at the fabric level and functioning throughout the clothing's lifecycle[6]. Besides sorting capabilities, RFID tags enable manufacturers to track product movement, collect usage data, facilitate quick self-checkouts in stores, and optimize washing settings with smart washing machines. However, concerns regarding privacy and health associated with RFID technology have been raised.

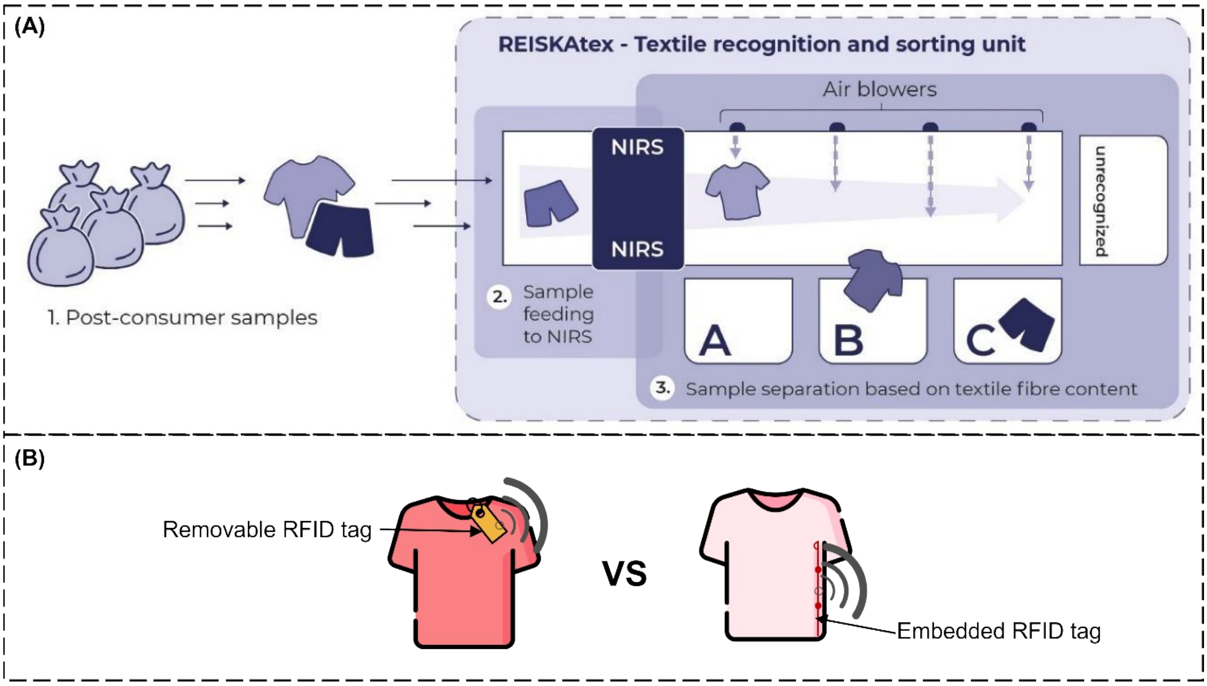

Figure S1. (A) The NIRS recognition and sorting lab pilot . Adapted with permission from [3]. Copyright 2019 Elsevier. **(B)** RFID tags can be either removable or embedded in the textile material.

S1.2 Dye removal and bleaching process

After sorting textile waste, dye removal and bleaching are necessary due to the diverse colors present, hindering reuse. Chemical bleaching employs oxidizing agents like hypochlorite[7] and hydrogen peroxide[8], along with reducing agents such as sodium sulfite[9] and sodium hydrosulfite[10]. However, these agents can damage cotton fibers and require additional wastewater treatment. Reductants partially degrade dyes, resulting in limited whiteness and potential yellowing, while oxidizing agents effectively dismantle dye molecules but may harm fibers[11]. Bleaching waste cotton using these agents is straightforward but time-intensive, necessitating environmental safeguards. Ozone and photocatalytic technologies offer effective methods for bleaching and decolorizing fabrics. Ozone breaks unsaturated bonds in dyes, while photocatalytic processes generate reactive substances that degrade dyes and oxidize cotton fibers[12]. Photocatalytic bleaching, although efficient, can alter fiber morphology and strength with prolonged use. However, it is environmentally friendly and energy efficient. Enzymatic biotechnology, using microbial enzymes, is also highly efficient and gentle, with minimal impact on fiber quality. Enzymatic treatment achieves high decolorization rates and preserves environmental integrity, making it an eco-friendly option for treating textile waste[13]. However, the specificity of biological enzymes limits their ability to break down only certain substances. Arooj et al. (successfully decolorized cotton fabrics of various colors at room temperature using ozone in a weakly acidic aqueous solution, resulting in fabrics with a whiteness level exceeding 60%[14]. Importantly, the ozone decolorization process eliminates the need for chemical additives, resulting in lower chemical oxygen demand and total suspended solids in the decolorization solution. This characteristic signifies a more environmentally friendly approach compared to traditional decolorization methods.

Reference:

1. C. Zhou, G. Han, B. K. Via, Y. Song, S. Gao and W. Jiang, *Textile Research Journal*, 2019, **89**, 3610-3616.
2. J.-R. Riba, R. Cantero, T. Canals and R. Puig, *Journal of Cleaner Production*, 2020, **272**, 123011.
3. K. Cura, N. Rintala, T. Kamppuri, E. Saarimäki and P. Heikkilä, *Recycling*, 2021, **6**, 11.
4. J. Rodgers and K. Beck, *Textile research journal*, 2009, **79**, 675-686.
5. J. Zhou, X. Zou and W. K. Wong, *International Journal of Clothing Science and Technology*, 2021, **34**, 29-40.
6. N. Denuwara, J. Maijala and M. Hakovirta, *Sustainability*, 2019, **11**, 6477.
7. H. Perkins, K. Rigakis and E. Crown, *Archives of Environmental Contamination and Toxicology*, 1996, **30**, 127-131.
8. S. Yousef, M. Tatariants, M. Tichonovas, Z. Sarwar, I. Jonuškienė and L. Kliucininkas, *Resources, Conservation and Recycling*, 2019, **145**, 359-369.
9. S. S. Liu, G. G. Fang, Y. J. Deng and Q. Wang, *Advanced Materials Research*, 2011, **291**, 1887-1891.
10. F.-N. He, X. Li, M.-K. Zhu, J.-H. Hu, Y.-J. Yuan, C.-C. Li and J.-J. Long, *Cellulose*, 2019, **26**, 4125-4142.
11. R. S. Araújo, C. C. Rezende, M. F. V. Marques, L. C. Ferreira, P. Russo, M. Emanuela Errico, R. Avolio, M. Avella and G. Gentile, *Journal of Applied Polymer Science*, 2017, **134**, 45060.
12. X. Su, W. Chen, Y. Han, D. Wang and J. Yao, *Applied Surface Science*, 2021, **536**, 147945.
13. S. A. S. Chatha, M. Asgher, S. Ali and A. I. Hussain, *Carbohydrate polymers*, 2012, **87**, 1476-1481.
14. F. Arooj, N. Ahmad, I. A. Shaikh and M. N. Chaudhry, *Textile Research Journal*, 2014, **84**, 527-538.