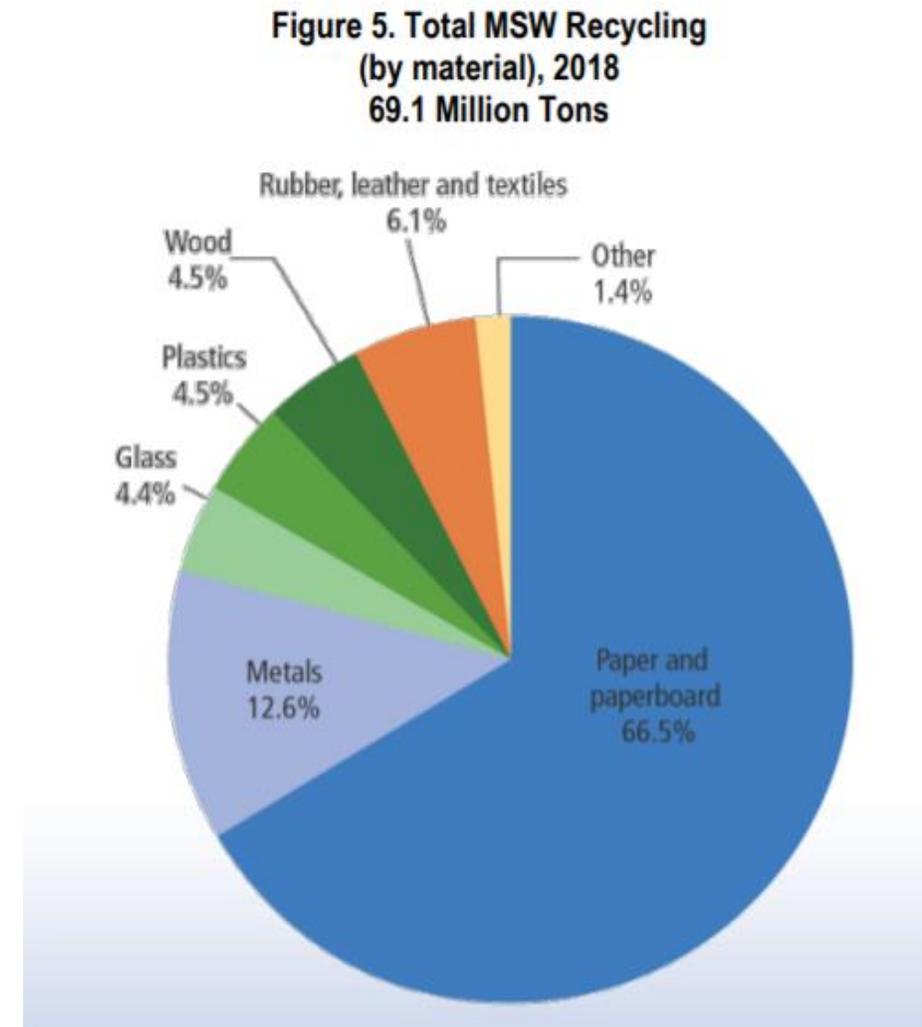
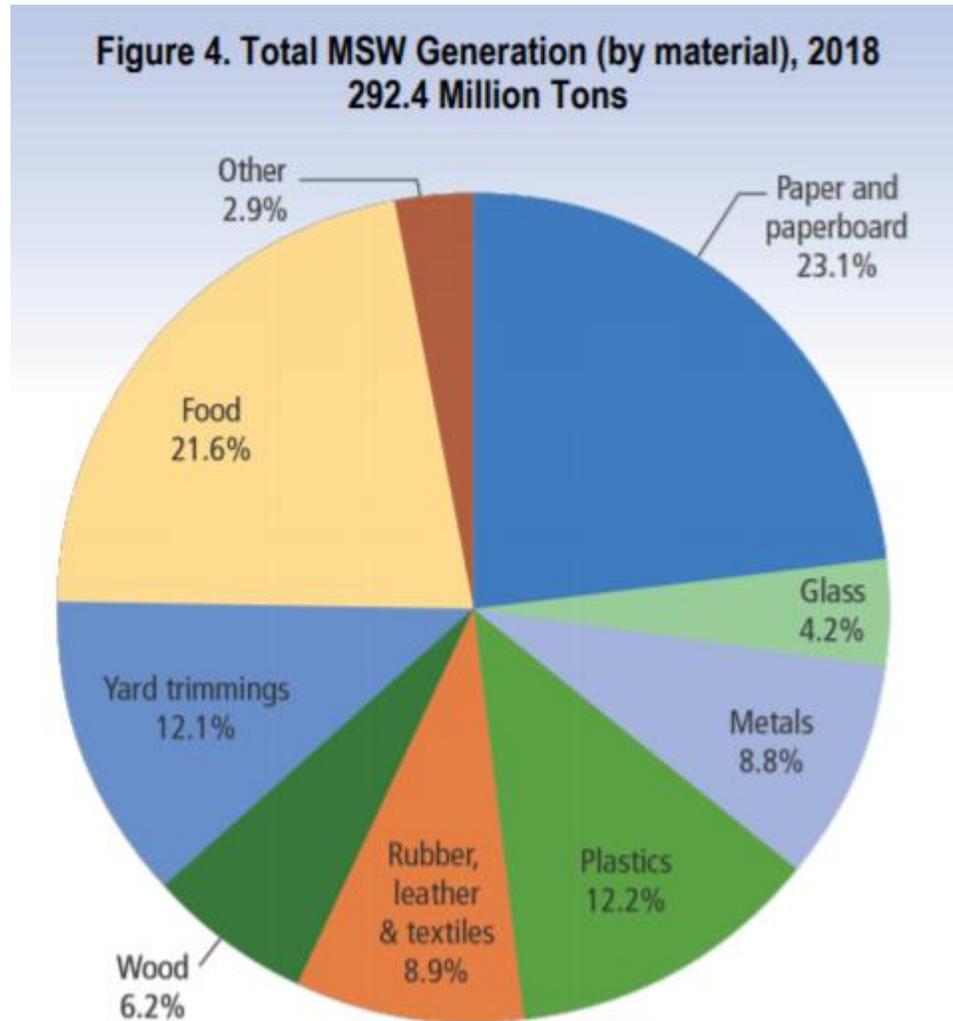


Waste Cotton Recycling and Reuse: Supply Chain and Environmental Impacts

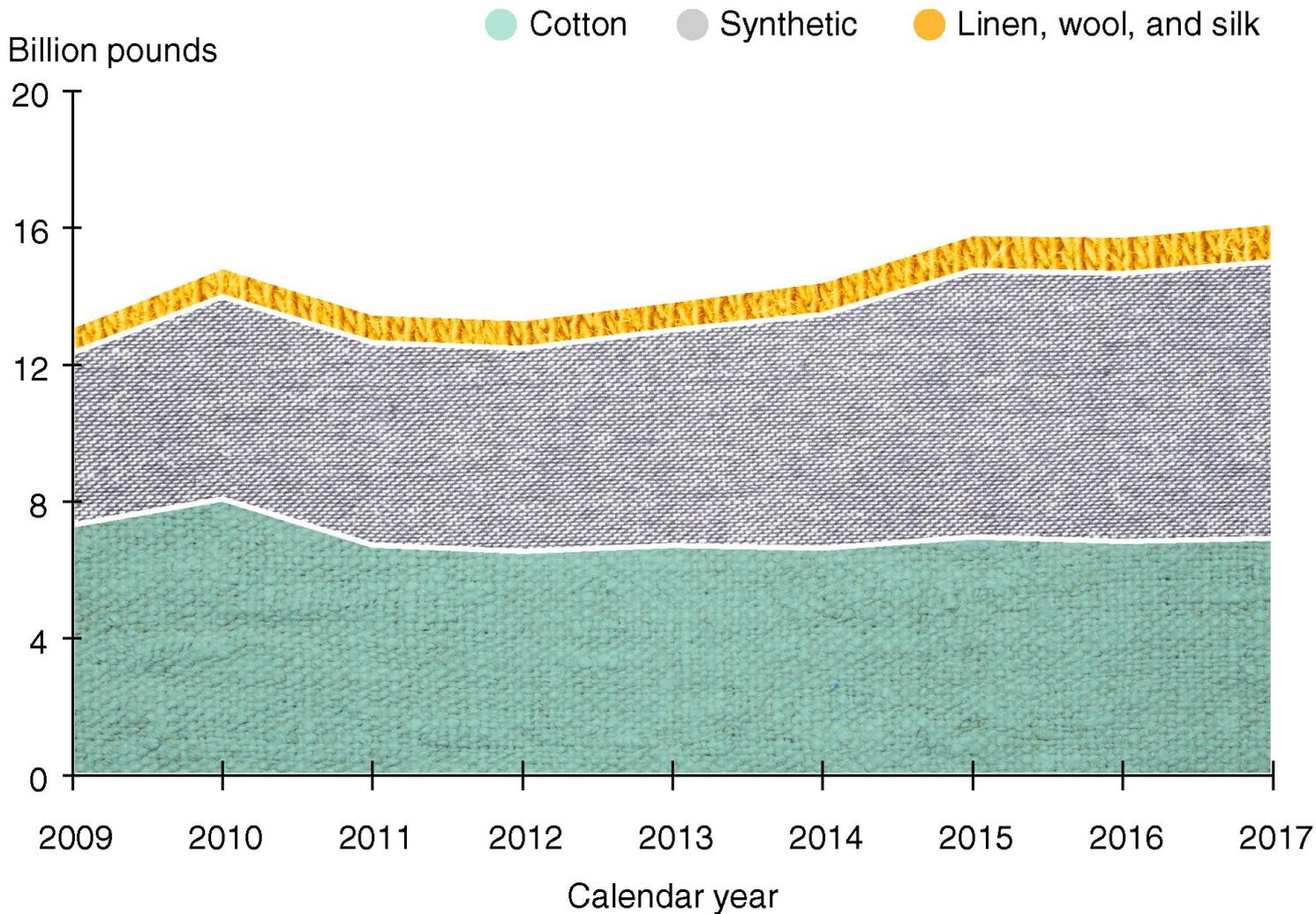
Yuan Yao

Assistant Professor of
Industrial Ecology and Sustainable Systems
Yale School of the Environment
Yale University



U.S. net imports of textiles and apparel, by fiber type

U.S. net imports



Notes: U.S. net imports = U.S. imports minus U.S. exports. Raw-fiber-equivalent pounds.
Sources: USDA, Economic Research Service using, U.S. Department of Commerce, U.S. Census Bureau Foreign Trade data.

Supporting Circular Economy for Waste Cotton



Pre-consumer waste

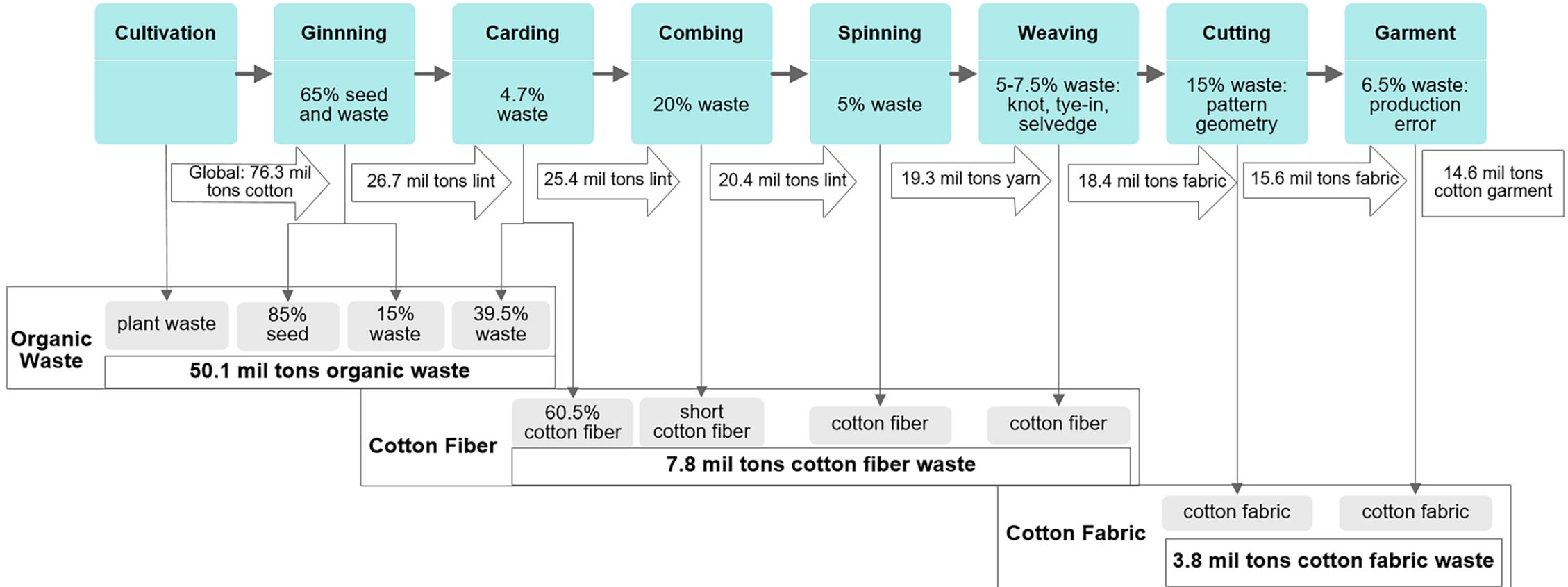
Photo: https://commons.wikimedia.org/wiki/File:QSMM_Cotton_waste_2616.JPG



Post-consumer waste

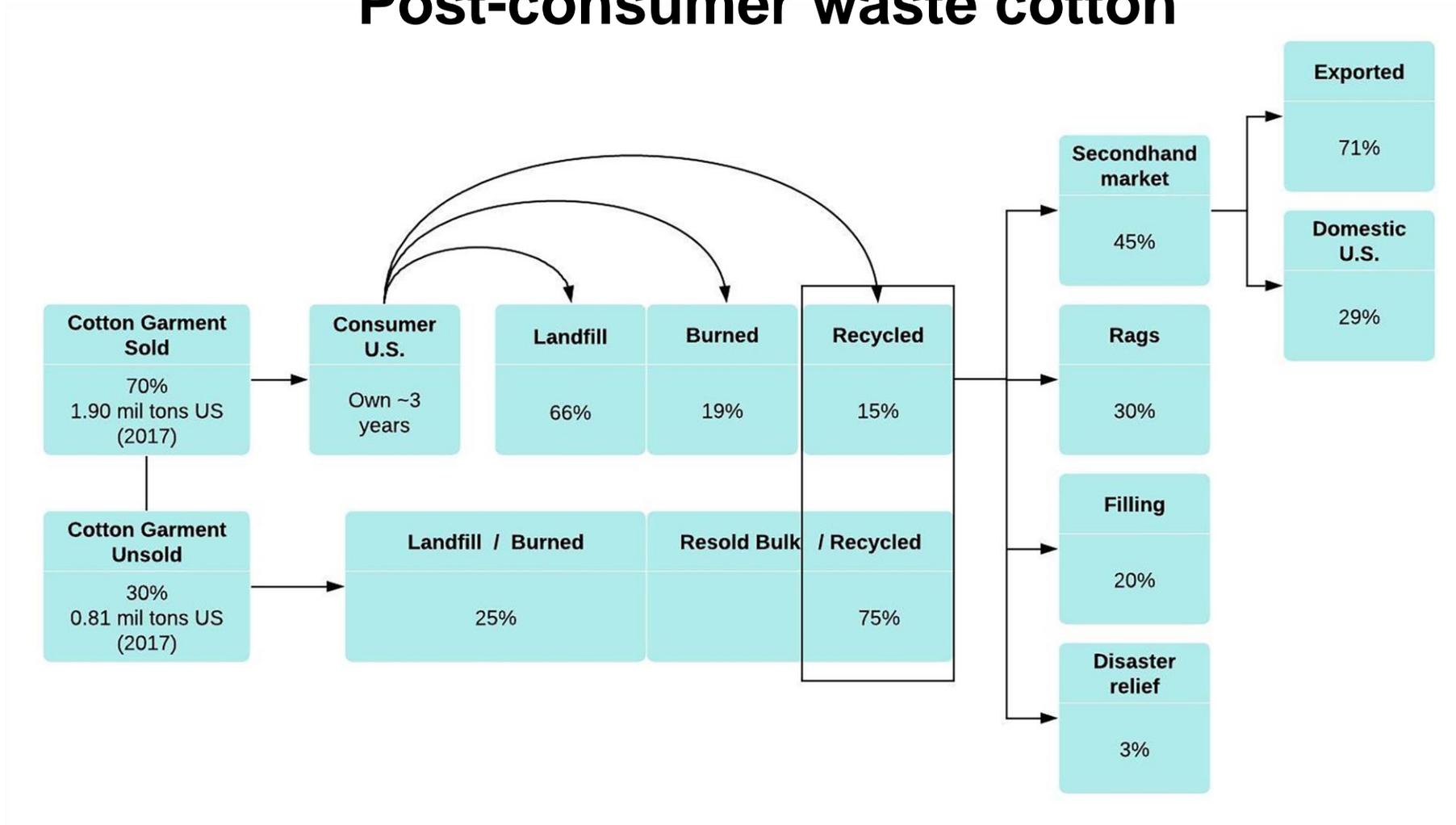
Photo from Pixnio

Pre-consumer waste cotton



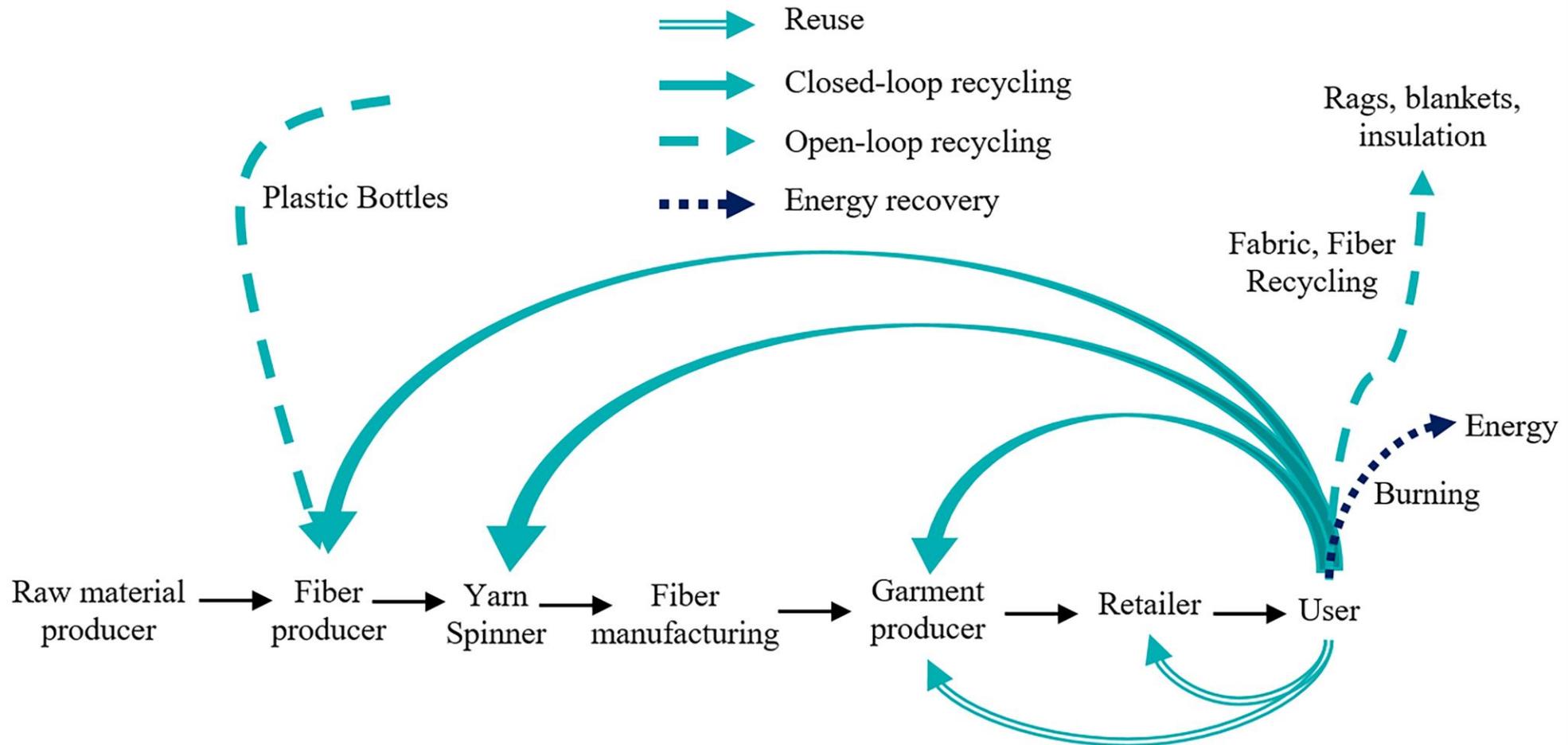
Annual fiber waste generated during global cotton garment production from August 2018 to July 2019.

Post-consumer waste cotton



Flow of post-consumer cotton garments in the United States per year.

Common end-of-life routes for textile



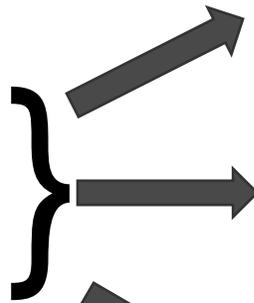
Alternative Pathways?



Photo:
https://commons.wikimedia.org/wiki/File:Q_SMM_Cotton_waste_2616.JPG



Photo from Pixnio



Composites – house insulation and automobile applications

Dissolving pulp – filter and paper applications

Succinic acid – food, pharmaceutical and industrial applications

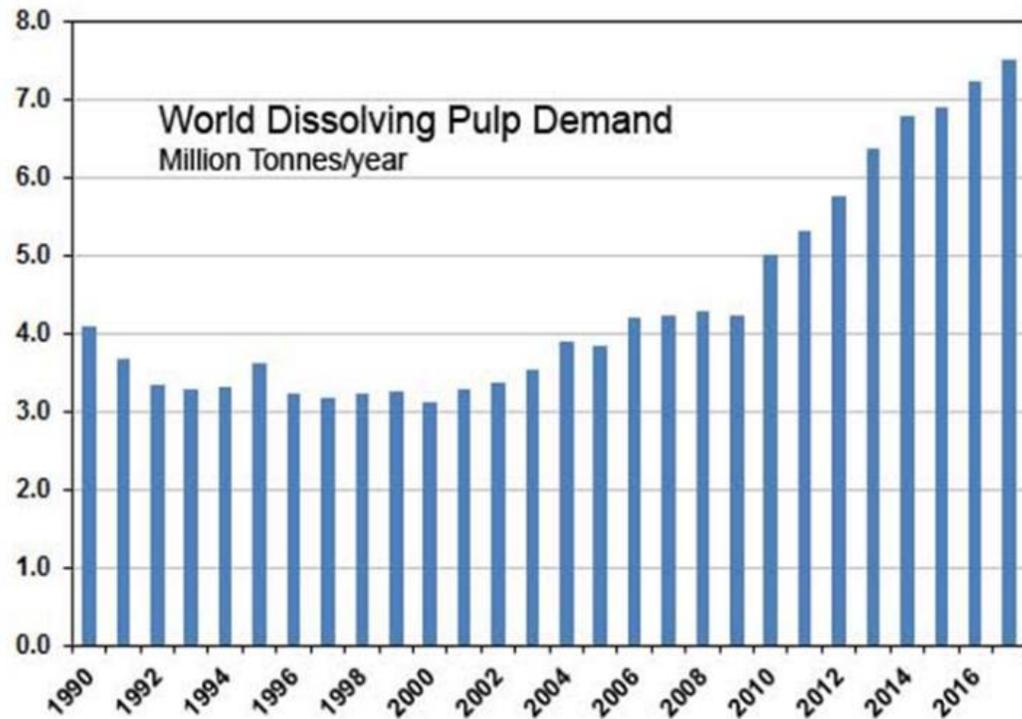
Table I. Chemical Process and Products from Cotton Waste with Possible Applications and their Virgin Alternative Products					
Chemical Process	Products	Applications	Virgin Products	Key Properties	References
Acid hydrolysis	Cellulose nanocrystals	Hydrogels. Biomedical applications.	Cellulose nanocrystals from other biomass	High crystallinity. Thermal stability. Length.	17,72,73
Anaerobic digestion	Biogas	Gas fuel	Natural gas	High heating value	65
Electrospinning method	Nanofibers	Nanomembrane filters. Protective clothing. Reinforced composites.	Nanofibers from fossil	Tenacity. Tensile strength. Elongation.	74
Enzymatic hydrolysis	Glucose (sugars)	Bioethanol as fuel, Co-producing energy on-site. Bioethanol as feedstock.	Ethanol made from corn or other biomass	Heating value if used as fuel, yields and purity used as feedstock.	65-67,75
Enzymatic hydrolysis	Polyethylene terephthalate (PET)	Plastics. Synthetic fibers.	Fossil-based PET	High mechanical resistance. Surface strength. Chemical resistance.	75
Enzymatic saccharification	Bacterial cellulose	Biomedicine. Cosmetics. Papermaking. Food ingredient. Textile industry.	Bacterial cellulose	High purity. High crystallinity. High degree of polymerization. High wet tensile strength. High water-holding capacity.	70,71,76
Gasification	Syngas and other by-products	Heat and/or power. Biofuel.	Fossil-based energy generation; fossil fuels	High heating value	77
Ionic liquids	Cellulose aerogels	Thermal insulation. Optical applications. Electrical applications. Additives. Encapsulation.	Silica aerogels	Hydrophobicity. Transparency. Brittleness.	69,78
Neutralization and partial dissolution of medical grade cotton (MGC) waste material	Self-reinforced composite	Self-reinforced composite for supporting material in fracture plaster	Fracture plaster	Interfacial adhesion. Stress transfer capability.	79

Life Cycle Assessment (LCA)

A concept and methodology to evaluate the environmental effects of a product or activity holistically, by analyzing the whole life cycle of a particular product, process, or activity (U.S. EPA, 1993).

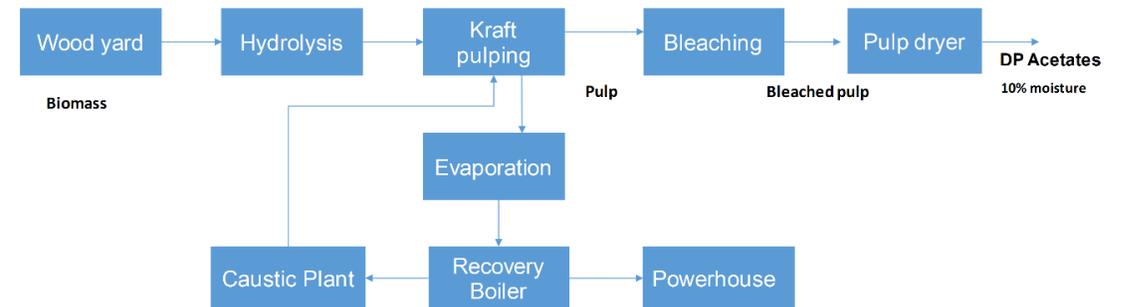


Waste Cotton to Dissolving Pulp Acetates and Cotton Pulp Based Paper

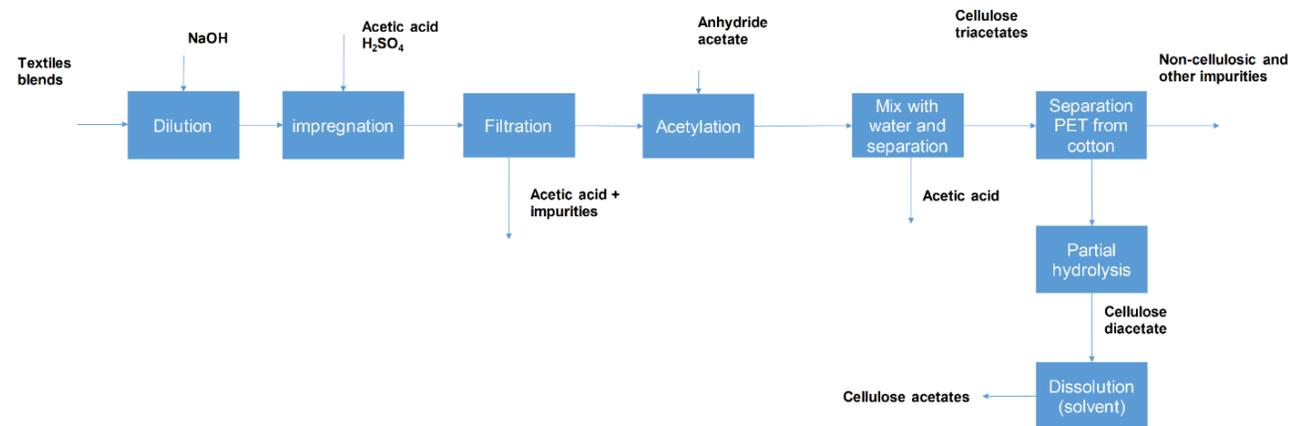


World dissolving pulp demand (million tonnes per year)

Plot based on data collected from:
RISI. Sappi. Roadbook Forward-Looking Statements and Regulation G; 2017.

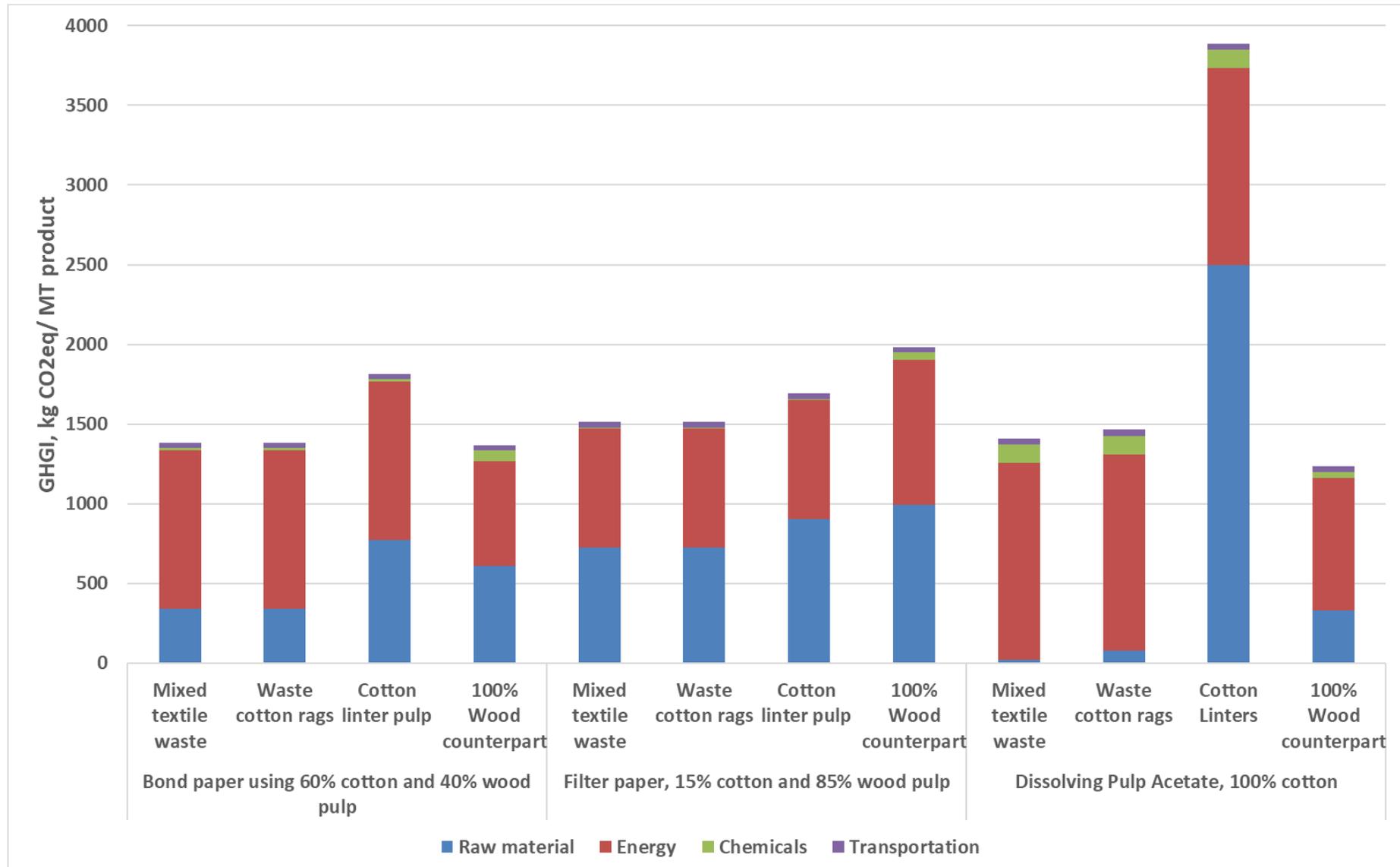


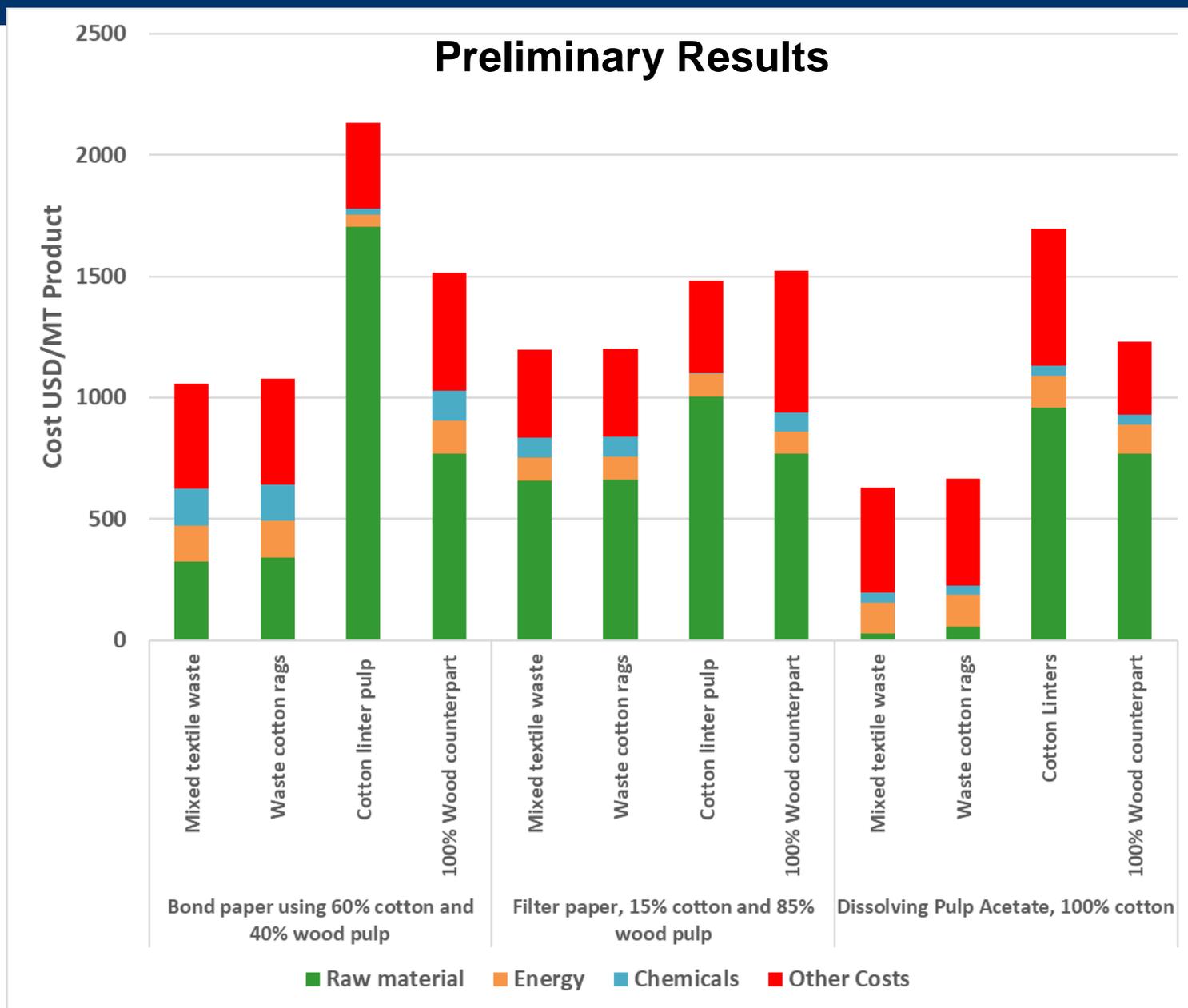
Dissolving pulp production from biomass



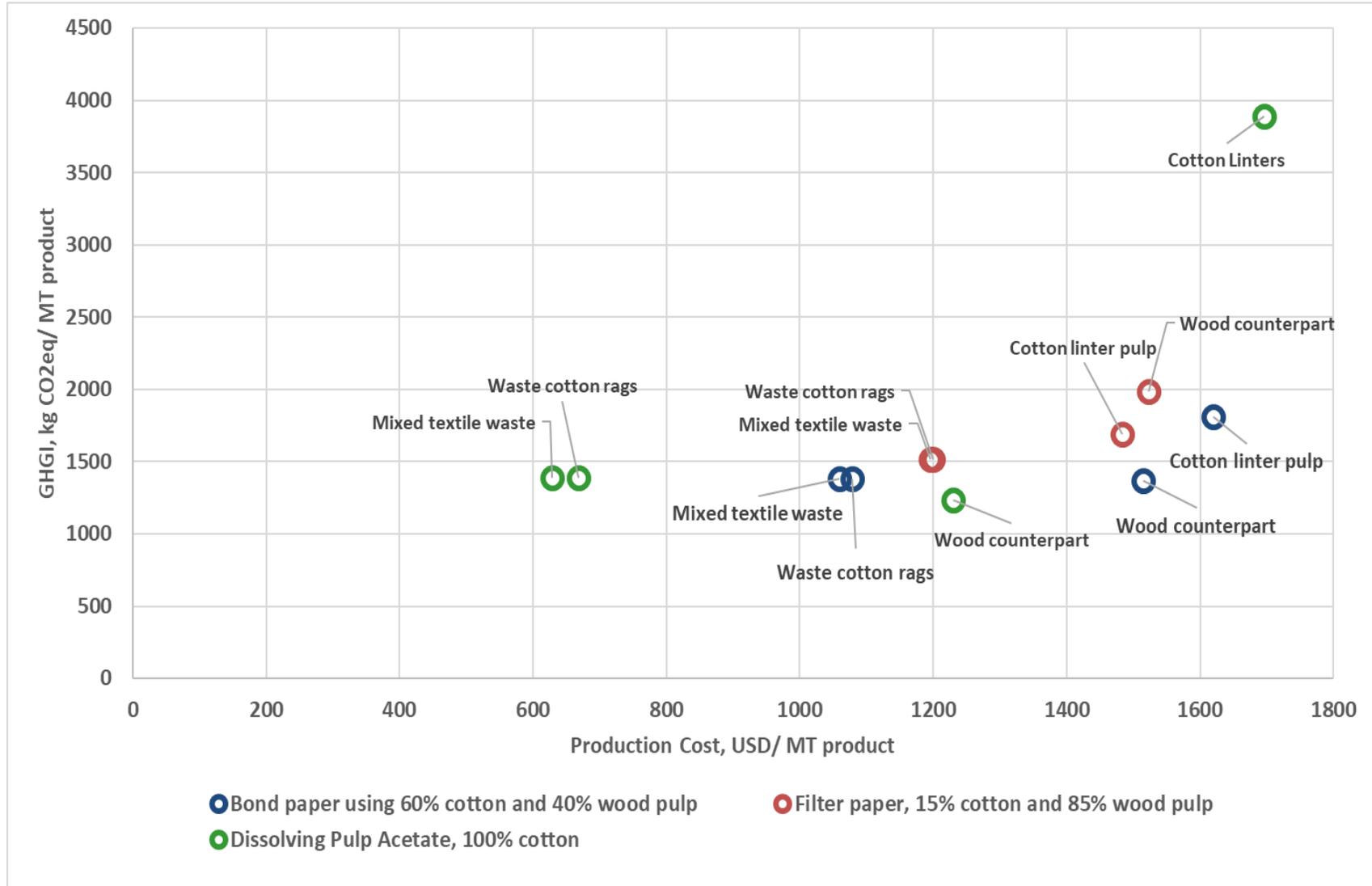
Proposed process flow for acetylation of textiles blends

Preliminary Results

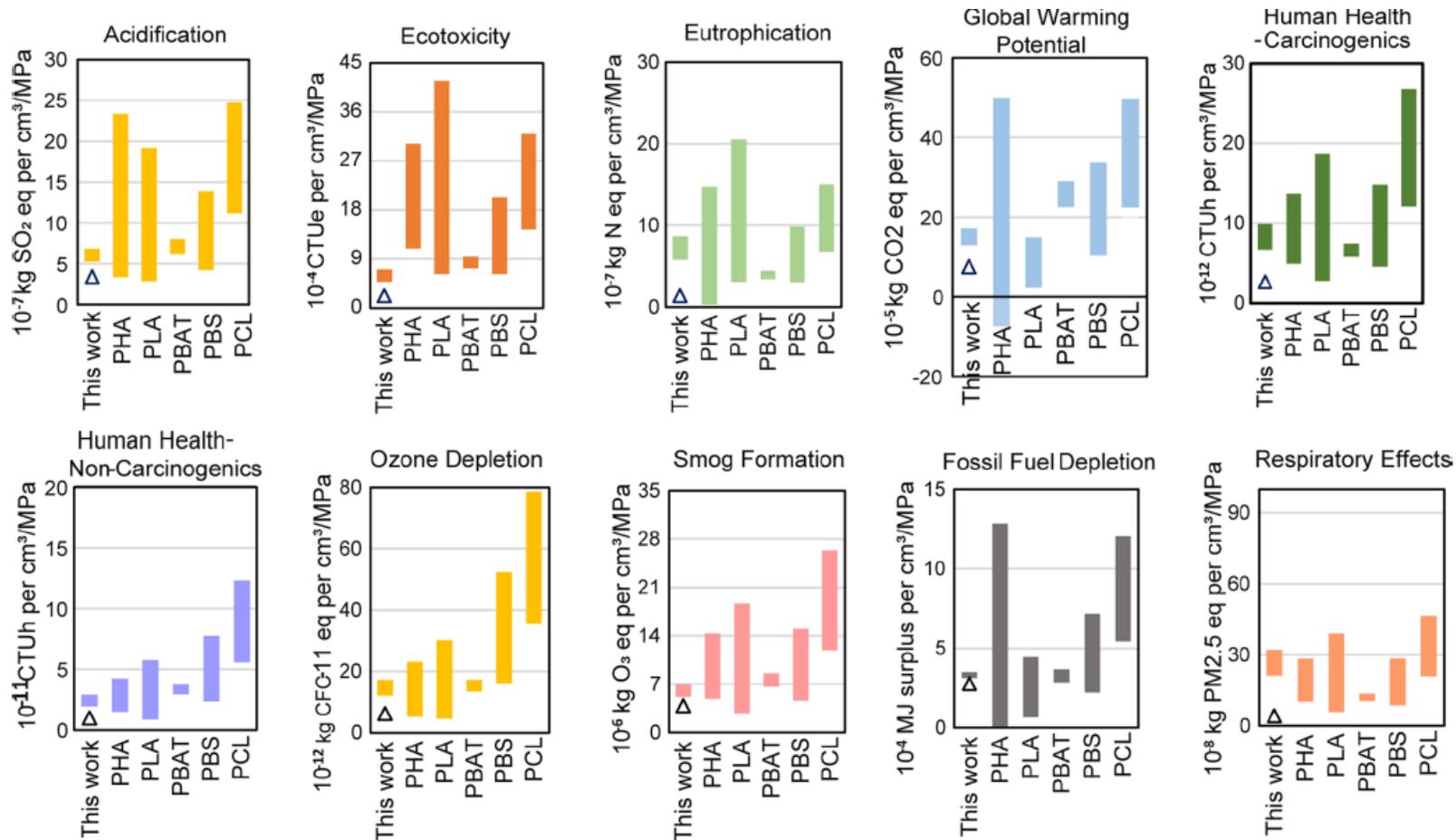




Preliminary Results



Other Environmental Impacts



Wood-based bioplastic (not cotton)

Need for Future Research

- A strong need to estimate the current actual material flows in the following areas to determine the flows and locations of the end-of-life cotton.
 - (1) waste and rejects from different industrial sectors
 - (2) retail wastes
 - (3) collections at donations centers
 - (4) end-of-life stages of cotton after their use
- LCA and techno-economic analysis for different end-of-life options of waste cotton.
- A better understanding of quality requirements and market potential for different applications of waste cotton.

Acknowledgements



Students and collaborators:

- Sara Johnson
- Darlene Echeverria
- Kristen E Tomberlin
- Dr. Richard Venditti
- Dr. Hasan Jameel

Yao Lab

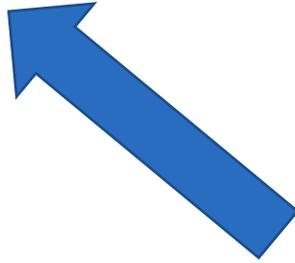


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y.yao@yale.edu

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THE ENVIRONMENT



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