Lignin valorization: Biomass deconstruction to synthesize high-performance polymers (NSF GCR CMMI 1934887)

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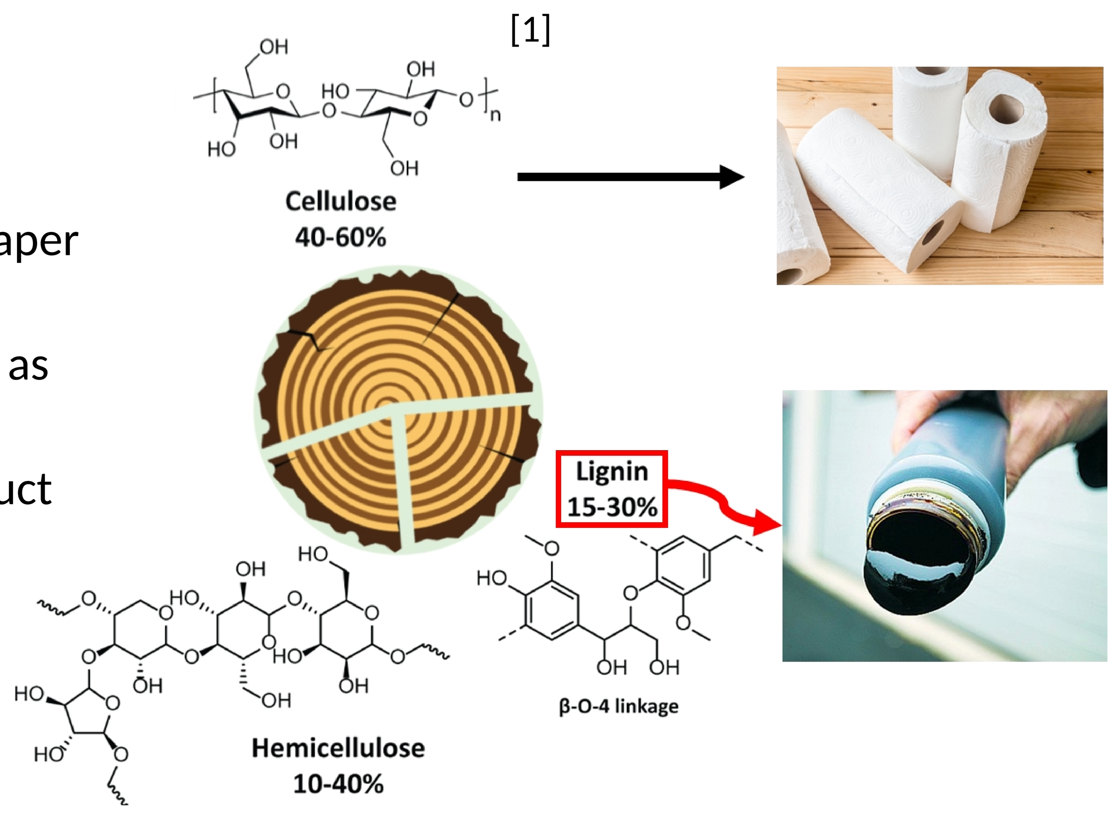
Goal

Develop sustainable, high–performance polymers from lignocellulosic biomass and link feedstock and deconstruction pathways to polymer properties

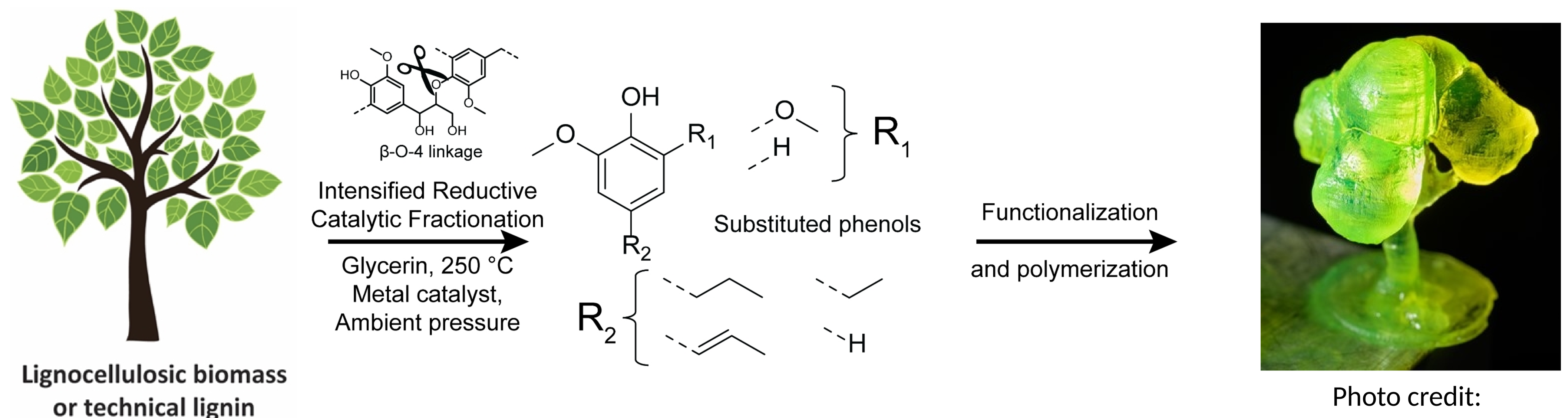
Brief overview

Biomass as a monomer source[1-4]

- Biomass consists of three primary components:
  - **Cellulose & hemicellulose:** Polysaccharides used in paper products and biofuels
  - **Lignin:** Complex, aromatic polymer; generally treated as waste
- **100 million tons of lignin separated annually** as a byproduct of the pulp & paper industry → >98% burned for heat
- **Significant economic opportunity with environmental benefits**



Lignin-derived bioplastics[5-9]



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Evan Krape/University of Delaware

Lignin deconstruction

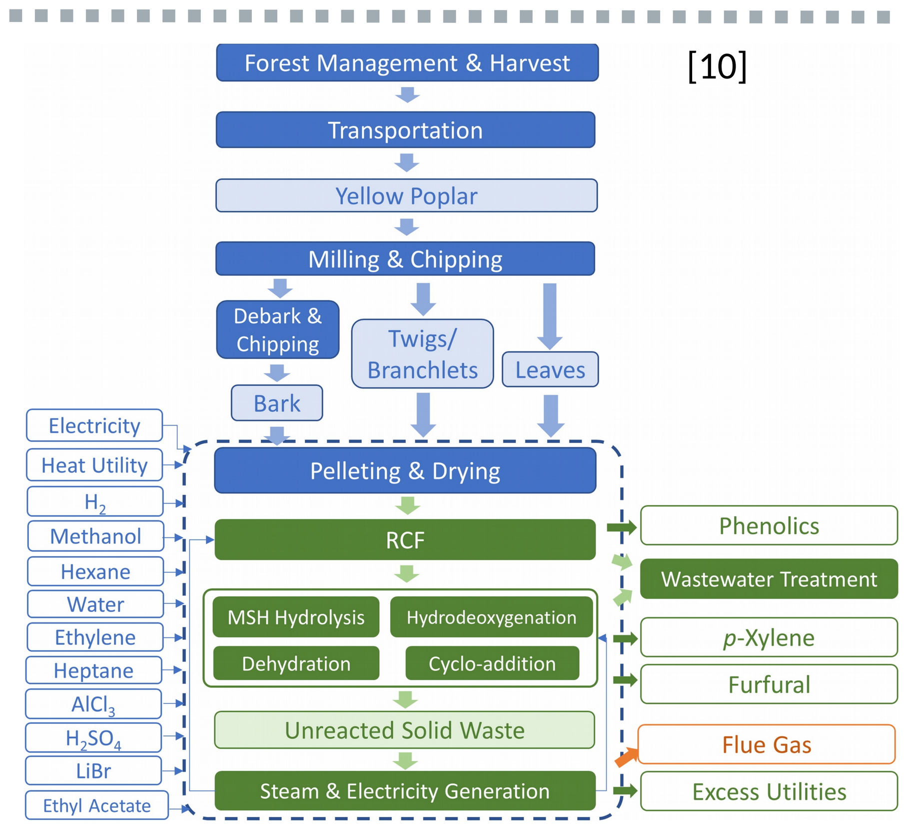
Process intensification for significantly reduced operating pressure (atmospheric pressure vs. ~1,500 psi) → **reduced energy costs, lower environmental footprint, and increased scalability**

Polymer synthesis

Leverage structure-property relationships to design high-performance materials using bio-derived mixtures

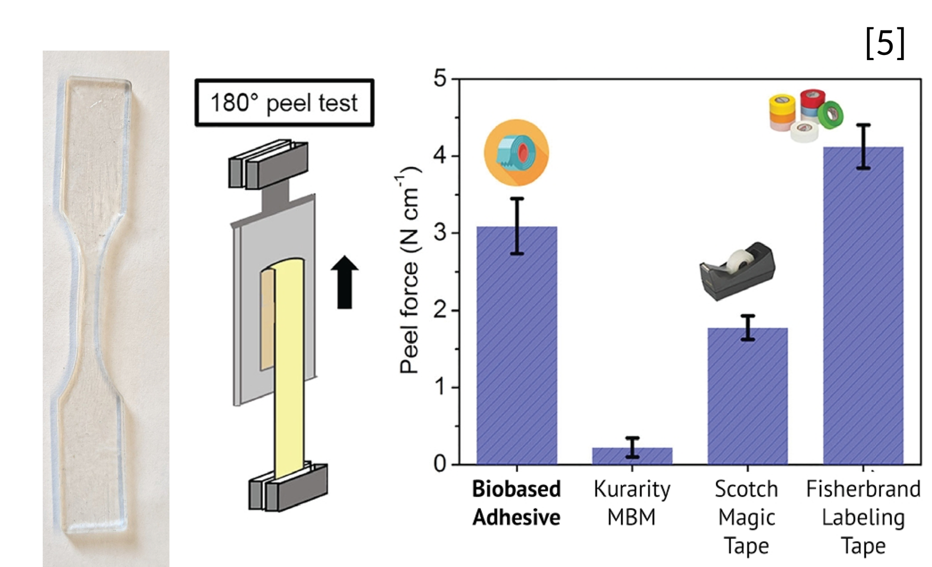
Integrated lignocellulosic biorefineries[10]

- **Life-cycle assessment (LCA):** computational method to determine environmental impacts of petroleum-based and bioderived chemicals and materials
- **Yellow poplar forest residue biorefinery modeled for LCA**
  - Abundant, low-cost lignocellulosic biomass feedstock
  - Reductive catalytic fractionation and molten salt hydrate processes
  - Primary products: *p*-xylene, furfural, and phenolics
- **Global warming potential reduction of 849 - 1,110 kg CO_2-eq/ton vs. petroleum-derived feedstocks,** dependent on the mixture of bark, leaves, and twigs/branchlets



Important achievements

- ✓ **Developed a safer, more scalable, and more economical deconstruction method**
- ✓ **Synthesized high-performance, lignin-derived polymers for applications such as pressure-sensitive adhesives**
- ✓ **Modeled integrated biorefinery with significantly lowered environmental impacts in comparison to analogous petrochemical production**

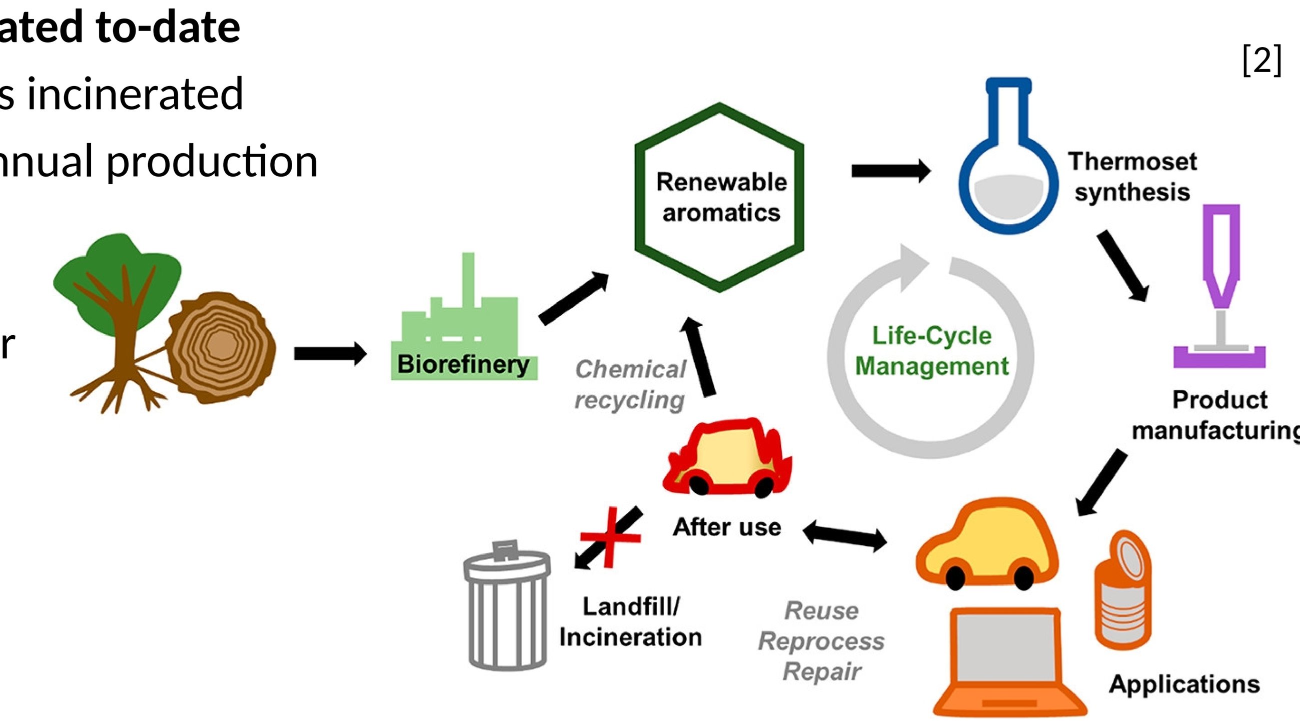


High-performance adhesives

Future work and collaboration opportunities

Life-cycle management[1,2]

- **~6.3 billion metric tons of plastic waste generated to-date**
  - Only ~9% has been recycled and ~12% was incinerated
  - Biobased plastics account for just 3% of annual production
- Sustainability requires balancing performance and environmental impacts across the polymer life cycle:
  - **Beginning:** Monomers sourced from renewable resources
  - **Middle:** Designed for durability and/or repairability
  - **End:** Recyclable or degradable after use



- **Collaboration through our NSF Growing Convergence Research team to connect catalytic deconstruction approaches, enzymatic functionalization strategies, non-invasive characterization techniques, and structure/property relationships in the production of more circular, high-performance polymers**

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