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Project title: Upscaling the conversion of lignin into functional materials through reactive extrusion	
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Abstract (approx. 200 words)**:**

Lignin esters represent a promising class of lignin-derived materials poised to replace petrochemical surfactants, thermoplastics, and carbon-fiber precursors. However, their commercial adoption is hindered by solvent-intensive routes that limit sustainability and economics. Our work introduces a continuous reactive extrusion platform that fundamentally redefines how lignin can be upgraded at industrially relevant throughputs. Using a twin-screw extruder, technical lignins are directly esterified with cyclic anhydrides at modest temperatures, eliminating the need for solvents, multi-step processes, or complex downstream purification.

The method demonstrates exceptional feedstock tolerance across diverse biorefinery lignins, providing supply-chain flexibility. Inline spectroscopic monitoring enables real-time process control to accelerate optimization and ensure consistent product quality. Full conversion is achieved in under 10 minutes, delivering a three-orders-of-magnitude increase in space-time yield compared to conventional batch processes. The resulting lignin esters exhibit tunable thermoplasticity and enhanced hydrophobicity while retaining intrinsic UV-shielding and antioxidant properties. These functionalities unlock lignin's application in coatings, thermoplastic formulations, and elastomeric materials.

By designing materials through a solvent-free, high-throughput process, this technology provides a drop-in pathway for biorefineries to valorize lignin streams. Its productivity, resource-efficiency, and compatibility with existing extrusion infrastructures position reactive extrusion as a key technology for bringing lignin-based functional materials into the market.

Key words: lignin esters, reactive extrusion, functional materials, biorefinery, process control