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Project title: Leveraging inorganic species in kraft black liquor to enable rapid oxidative crosslinking and morphology control in kraft lignin derived hard carbons

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Abstract (approx. 200 words):

Kraft lignin (KL) is a large-volume, carbon-rich byproduct of the pulp industry, making it an attractive feedstock for renewable carbon materials. However, conventional routes to KL-derived carbon start with high purity KL, obtained through harsh acid recovery from black liquor at significant cost. These purified particles also soften, foam and agglomerate during carbonization, damaging pyrolysis equipment, reducing carbon yield and preventing control over particle morphology. To address this, industry uses very slow oxidative stabilization pretreatments of KL in air prior to carbonization, often combined with mechanical compaction and grinding steps, and/or external chemical crosslinkers. These measures mitigate melt-related issues but add substantial processing, energy and cost.

We invert this paradigm. Rather than removing black liquor inorganics, we deliberately retain them in KL, where they act as catalytic crosslinking agents. During thermal pretreatment in air, these inorganics rapidly crosslink KL, giving precise control over carbon particle morphology without external crosslinkers or long stabilization times. The stabilized particles are washed and carbonized into a hard carbon that outperforms carbon from industrial low-ash KL and matches commercial hard carbon benchmarks as anode material in Li- and Na-ion battery testing. The inorganics recovered during washing can be recycled back to the pulp mill, adding circularity to the process. We demonstrate this using spherical KL microparticles recovered from black liquor by membrane filtration or CO_2-assisted precipitation. Overall, this study demonstrates how typically undesirable inorganic impurities can be leveraged to simplify KL thermal conversion into carbon materials, offering a scalable route for energy storage and other applications for which particle size and morphology are critical.

Reference: Pauls, G et al. (2026). Inorganics from kraft black liquor enable rapid oxidative crosslinking and morphology control in lignin derived hard carbons. *Bioresource Technology*, *447*, 134177. https://doi.org/10.1016/J.BIORTECH.2026.134177

Key words:
Kraft lignin; Inorganics; Thermal mobility; Cross-linking; Carbonization; Hard carbon; Anode; Battery; Na-ion