Quantifying Atmospheric Carbon Removal at Pulp and Paper Mills: A Life Cycle Assessment Across System Boundaries

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Abstract:

The pulp and paper industry is a promising yet underexplored platform for large-scale carbon dioxide removal (CDR) due to its use of biogenic feedstocks and production of concentrated CO_2 emissions from point sources. This study presents the first comprehensive life cycle assessment (LCA) of retrofitting an amine-based carbon capture and storage (CCS) system into a representative virgin kraft pulp and paper mill in the Southeastern U.S. We evaluate carbon removal across five system configurations, applying both static and dynamic LCA methods under multiple functional units: CO_2 captured, biomass input, and paper output. Results show that CCS retrofits can convert a conventional mill from a net emitter into a net carbon sink, with total removal ranging from 0.7 to 2.3 metric tonnes of CO_2 per tonne of paper produced. When carbon removal is normalized to the quantity of biogenic CO_2 captured—a narrow, gate-to-gate system boundary that considers only CCS facility emissions—removal efficiencies reached as high as 92%. The use of such narrow boundaries aligns with precedents in traditional LCA methodology, where gate-to-gate assessments are commonly applied to isolate process-level performance and allocate emissions accordingly, providing a consistent basis for comparison across technologies. Under broader cradle-to-grave boundaries—which begin tracking carbon at the point of its physical removal from the atmosphere via photosynthesis in the forest, and extend to include upstream forest operations, mill-wide emissions, and downstream product decomposition—efficiencies declined, ranging from 17% to 46% under static assumptions and dropping to 12% when accounting for dynamic biogenic carbon fluxes over time. These results underscore how system boundary definitions influence reported outcomes, while also illustrating the complementary roles of narrow and broad perspectives for different decision-making contexts.