Analysis of Carbon Capture in Lignocellulosic Biorefineries

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Project Goals: This project aims to use modeling and optimization methods to evaluate the effect of pretreatment method and feedstock selection on the performance of an ethanol biorefinery with carbon capture. Performance is evaluated using economic, environmental, and energetic metrics.

Bioenergy with carbon capture and sequestration (BECCS) is a widely studied technology for global warming mitigation. While industrial power plants that use coal or natural gas emit CO_2 only in flue gas, ethanol biorefineries have multiple point sources of CO_2 emissions: nearly pure CO_2 from fermentation, biogas from anaerobic digestion, and flue gas from solid residue combustion. The relative amounts of CO_2 emitted from each of these point sources depend on what feedstocks and pretreatment methods are used. The solid residues and biogas are typically burnt in biorefineries to meet their energy demand, and excess electricity is sold to the grid. However, at high rates of carbon capture, electricity would have to be purchased, and thus the biorefineries would no longer be energetically self-sufficient.

Industrial power plants have the advantage of economies of scale, but large biorefineries would require transport of feedstocks from farther away, which increases both feedstock cost and emissions. At these large distances, biomass can be transported a short distance to a processing depot where it is densified into pellets prior to transportation to the biorefinery by either truck or rail. This densification at depots decreases the transportation cost increase associated with greater distances. Even with depots, there is significant variation in reported cost-optimal biorefinery capacities, and even more variation for biorefineries with carbon capture. The supply chain is also important for economic and energetic considerations, as emissions from growth, harvesting, and transportation affect the greenhouse gas balance and energy consumption of the entire system.

A superstructure-based optimization model is used that embeds all possible selections of technologies, and solved for the lowest-cost solution. Sensitivity analyses are performed on carbon sequestration credits, carbon capture rates, and biorefinery capacity to evaluate the economic, energetic, and environmental performance of biorefineries using different combinations of feedstocks and pretreatments.

Pretreatment methods and feedstocks that lead to high carbon emissions from fermentation and anaerobic digestion have lower average carbon capture costs. Biorefineries with high biomass to ethanol yields can capture high percentages of the carbon in the feedstock if energy is purchased,

but less excess energy available from residue combustion limits carbon capture when energetic self-sufficiency is required. Biorefineries with low energy requirements and that use feedstocks with high energy content can capture the highest rates of carbon. At high capacities that use processing depots and rail transportation, increasing capacity has minimal impact on the greenhouse gas balance and energy consumption of the system. Depending on the specific configuration of the biorefinery, capture from fermentation only or capture from fermentation and biogas is required to achieve net-negative carbon emissions. In all cases studied, the energy consumption of the supply chain and biorefinery does exceed the energy in the ethanol produced.

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