Expanding the biomass sugars platform: An investigation of sugar separation and purification techniques in the context of an integrated biomass processing refinery

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This project focuses on identifying opportunities to use lignocellulosic biomass to expand the existing industrial sugars platform. The objective is to anticipate and investigate the potential to produce and utilize biomass-derived sugar products beyond the sugar cane - and starch-based hexose sugar products currently available.

An analysis of the existing sugar market was performed to identify the strongest candidates for biomass-based products. Results show that renewable energy and energy efficiency-driven changes are dramatically altering world sugar production and utilization patterns and suggest that D-xylose sugar products and D-xylose-based chemicals have promise in the marketplace provided that their costs of production are sufficiently low.

We report here on work examining and comparatively evaluating a variety of separation and purification techniques that could be incorporated as prospective unit operations of a process train to produce D-xylose-rich product stream(s) from slipstreams taken from an enzymatic cellulose hydrolysis-based biomass-to-ethanol (bioethanol) process, using the NREL enzyme-based process model as the reference bioethanol process case. The D-xylose-rich slipstream from this conceptual bioethanol processing plant is dilute-acid pretreated corn stover hemicellulose hydrolyzate liquid that has been treated with lime and ion exchanged to reduce sulfuric acid and acetic acid levels. The composition of this slipstream is summarized in Table 1. Small amounts (ppm range) of xylitol, solubilized lignin, glycerol, corn steep liquor, cellulose, xylan, arabinan, galactan, mannan, tar, and ash are assumed to be present as the result of recycling process water.

Table 1. Model composition of sugar slipstream from enzyme-based biomass-to-ethanol process

Component	**Concentration (g/L)**
Glucose	7.9
Xylose	52.1
Arabinose	6.7
Galactose	3.6
Mannose	0.5
Sugar Oligomers	7.4
Soluble Solids	18.3
Extractives	11.9
Furfural	4.6
HMF	0.4
Lactic Acid	2.7
Acetic Acid	0.7

The isolation of D-xylose from a mixed stream of sugars and acids is challenging due to the structural similarity of hexoses and pentoses. We propose using a three-step separation train consisting of filtration, concentration, and purification unit operations. A membrane filtration system is first used to eliminate carry-over of colloidal particles, insoluble solids, and other impurities commonly found in biomass hydrolysates. Using a membrane system in front of the concentration and purification steps improves the downstream processing economics as these steps become more efficient and reliable. Concentration techniques being evaluated include multi-effect evaporation as well as a novel dewatering technique based on the differing affinities for water that secondary and tertiary amines exhibit at different temperatures. Finally, preparative liquid chromatography and fractional crystallization are being evaluated for the isolation and final purification of D-xylose from the other sugar components. Preliminary evaluations suggest that a preparative liquid chromatography technique known as simulated moving bed chromatography is the most economically feasible for an industrial-scale process. Simulated moving bed (SMB) simulates countercurrent movement of the solid (adsorbent) and liquid phases by shifting inlet and outlet streams on fixed bed columns in a semicontinuous manner. SMB chromatography is an industrially-proven separations technology that is being used extensively in the sugar industry to separate glucose and fructose. While only binary separations are possible in a single step of SMB chromatography, multicomponent separations are possible by cascading SMB systems.

The combinations of these methods that appear the most favorable are being rigorously evaluated using ASPEN Plus process simulation models. Technoeconomic analyses based on the results of these simulations will then be used to select the most economically feasible processing options. The simulation results and the implications of the technoeconomic modeling on the development of a biorefinery producing a mixed slate of ethanol, D-xylose, steam and electricity bioenergy products will be discussed.