Valorization of switchgrass into functional carbon materials and natural emulsifiers

*Yilin Li[1], Yiming Feng[2,3], Feng Lin[4], Haibo Huang[1]**

1 Department of Food Science and Technology, Virginia Tech, 1230 Washington St SW, Blacksburg, VA 24061, United States

2 Department of Biological Systems Engineering, Virginia Tech, 1230 Washington St SW, Blacksburg, VA 24061, United States

3 Virginia Seafood Agricultural Research and Extension Center, Virginia Tech, 15 Rudd Ln, Hampton, VA 23669, United States

4 Department of Chemistry, Virginia Tech, 1040 Drillfield Dr, Blacksburg, VA 24061, United States

** Corresponding author: huang151@vt.edu*

Switchgrass has been recognized as a promising biomass crops due to its high yield and abundant availability. However, the current utilization of switchgrass remains limited to low-value uses, which limits its broader adoption and economic viability. This study aims to convert switchgrass into high-value, large-volume commodity products, i.e., hard carbon (HC) and natural emulsifiers, and investigate the economic feasibility at an industrial scale. A hydrothermal-assisted carbonization was developed to convert switchgrass into battery-grade HC for sodium-ion batteries. The material characterization showed that the hydrothermal treatment effectively removed hemicellulose and impurities, which was crucial in enhancing electrochemical performance of the resulted HC. The optimal HC exhibited a high specific capacity of 313.4 mAh/g at 100 mA/g, a commendable ICE of 84.8%, and excellent cycling stability. In addition, a techno-economic analysis (TEA) was performed to assess the economic feasibility of producing HC from switchgrass. The TEA results showed that annually producing 110,000 tonnes of HC requires a total capital investment of $90.2 million, with a minimum carbon selling price (MCSP) of $1.7/kg. Incorporating an internal wastewater treatment and recycling system raised the capital to $125 million but significantly reduced water and energy consumptions, lowering the MCSP to $1.6/kg. This price is notably lower than current market prices, suggesting an economically viable process. Meanwhile, hemicelluloses released during hydrothermal treatment as a processing byproduct, but it can be valorized to natural emulsifiers. The hemicelluloses were recovered through graded ethanol precipitation and freeze drying, and their structural characteristics and emulsifying properties were analyzed to determine their potential application as natural emulsifiers in food systems. The experimental results showed that high-molecular-weight hemicellulose exhibited superior emulsifying performance. The optimized hemicellulose delivered an outstanding emulsifying activity index of 100.4 m^2/g and maintained stable droplet sizes remaining below 2 μm after 21 days. Overall, this research valorized switchgrass into functional HC and natural emulsifiers, highlighting an economically viable opportunity to support energy storage system and food industry.