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Sweet Greens: Challenges and Opportunities for Converting Agricultural Waste into Biofuels

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The U.S. has the capacity to generate more than a billion tons of agricultural waste per year, enough to satisfy 24% of US energy needs or to completely replace petroleum carbon in domestic plastics use. Unlocking this potential requires reducing the costs of converting biomass polymers into sugar monomers that can be converted into many of the fuels, chemicals, and materials we use every day. My team's journey began by studying the interaction between biopolymer crystallinity and reactivity, revealing new insights that have escaped the research community for 80 years. In particular, we found that energy intensive cellulose decrystallization is reversed as soon as the cellulose contacts water, accounting for the low reactivity observed for decades even for completely amorphized cellulose. To address the spontaneous recrystallization, we tested ethanolysis and the use of water-structure disrupting salts to preserve cellulose in a decrystallized state during hydrolysis. Follow-on experiments showed that suppressing recrystallization could only partially explain benefits observed with salt promotion. Carefully selected salts can balance the zeta potential of the cellulose surface, thereby allowing greater contact between the cellulose and the soluble acid catalyst. Thus inspired, we tested the use of salts to promote the enzyme-catalyzed hydrolysis of cellulose, finding remarkable promotion of hydrolysis rate which reached 100% conversion in several hours. Applying this understanding to bamboo as a fast-growing energy crop, we found that salts behave differently with whole biomass than model compounds. Fortunately, we used our understanding of recrystallization to develop two-step treatments that achieved quantitative sugar yields from bamboo. Realizing that enzymes cannot be re-used, we then studied the use of recoverable solid acids for biomass hydrolysis, finding that cellulose hydrolysis is difficult to achieve without degradation. Hemicellulose can be selectively hydrolyzed to sugars when solid acids are combined with surface engineering to overcome acid-biomass electrostatic repulsion. Our work answers longstanding mysteries and opens new doors to biomass conversion to sugars to unlock their potential as a renewable carbon source.

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Prof. Michael Timko is a Professor of Chemical Engineering at Worcester Polytechnic Institute (WPI). Dr. Timko's main research interests involve the study of new technologies for the production of sustainable fuels, chemicals, and materials. He is author of more than 120 peer-reviewed journal articles and a recipient of a National Science Foundation's CAREER award, the American Chemical Society's Glenn Research Award, and a Fulbright Award. Prof. Timko is on the editorial boards of Sustainable Chemistry and Global Challenges; co-inventor on five patents; and scientific founder of River Otter Renewables. He is co-PI of an NSF Research Training Grant on the combination of chemical sciences, data sciences, and social sciences for advancing the circular economy. Prior to joining WPI, Dr. Timko was a Principal Engineer at Aerodyne Research Inc. and a Research Engineer at the Massachusetts Institute of Technology (MIT). His training is in chemical engineering and chemical physics at The Ohio State University (B.S.), MIT (M.S. and Ph.D.), and Harvard University (post-doc).