**Commercializing enzymatic biomass conversion technologies:
Opportunities for sugar, ethanol, and power**

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Commercializing enzymatic hydrolysis-based technologies for the conversion of plant biomass such as agricultural residues to a variety of fuels, chemicals and bioenergy products holds the promise of providing significant environmental, economic, and strategic benefits to the United States of America. This talk will focus on the opportunities and challenges inherent in developing and deploying multi-product biomass conversion biorefineries. As a starting point for analysis, it is assumed that such biorefineries will be built off of large-scale biomass ethanol (bioethanol) production facilities that are already producing ethanol and electrical power. Biomass-derived sugar(s) represents a conceptual third product that such a plant could be producing to diversify its product slate.

Historically, processes for ethanol production from lignocellulosic feedstocks have relied mostly on acid-catalyzed hydrolysis to depolymerize the biomass carbohydrates components hemicellulose and cellulose. The results achieved in the past 15 years, however, coupled with the tremendous advances in biocatalyst development that the modern biotechnology revolution has enabled, have led the United States Department of Energy (USDOE), the National Renewable Energy Laboratory (NREL), and many other researchers to explore potentially higher-yield process routes for the conversion of biomass based on biologically-catalyzed cellulose hydrolysis. In particular, NREL, USDOE and others believe that processes based on a combination of thermochemically- and enzymatically-mediated carbohydrate hydrolysis reactions offer better long-term potential for minimizing the cost of ethanol production from lignocellulosic feedstocks than processes based on thermochemical acid hydrolysis alone.

The technical feasibility of converting cellulosic materials to ethanol has been recognized since the late 1800s, and a number of pilot plant demonstrations based on various forms of acid hydrolysis were pursued in the last 100 years. Despite these efforts, however, commercialization of ethanol produced from cellulosic materials remains elusive, with no large-scale commercial production facilities (i.e., plants producing more than 40 million gallons of ethanol per year) yet in operation. Examining how current starch-based ethanol production facilities operate and why previous efforts to commercialize ethanol from lignocellulose have often failed to succeed in the marketplace provides insight into what steps need to be taken to make enzyme-based ethanol production from biomass a commercial success. These analyses suggest that strategies to bring down processing costs and business risks by co-locating and producing additional value-added products beyond ethanol and power are needed to facilitate technology deployment.

Commercializing enzyme-based biomass conversion to ethanol and power at very large volumes (i.e., for non-niche situations) will require overcoming challenging economics. The cost of delivered feedstock, the cost of cellulase enzymes to the process, and overall capital costs are key contributors to the overall process' economics. Thus, these are the areas where cost reductions are especially needed. Strategies to mitigate processing costs include co-locating the plant adjacent to existing facilities to reduce capital costs, e.g., for power generation and other infrastructure components. Beyond this, diversifying the product slate of the plant, for example by producing sugar- or lignin-based co-products, is another approach to potentially reduce production costs and market risks.

There are a variety of additional issues beyond the economics of the core enzymatic conversion technology that must also be resolved. For example, the methods and infrastructure must be developed to supply feedstock(s) that meet appropriate conversion plant specifications. Equally important, the fully integrated conversion technology needs to be well understood and demonstrated to be robust under realistic large-scale industrial processing conditions.

This talk will describe these issues in greater detail from the perspective of the "Enzyme Sugar Platform" (ESP) project being led by NREL and will outline the steps that the USDOE, NREL and others are taking to facilitate commercialization of multi-product biorefinery technology. The ESP project's goal is to develop technology for the conversion of corn stover to fuel ethanol, power, and additional co-products. The cellulose conversion technology used in the project will be based on improved, lower cost, higher efficacy cellulase enzymes currently being developed by industry. The other main technical components of the project and its schedule will be described. Discussion will highlight recent progress in evaluating potential co-location scenarios to bring down overall capital costs.