Quick Facts

NREL provided two leading enzyme companies, Genencor and Novozymes, with access to its innovative biomass characterization, pretreatment, and process integration research, which led to lower enzyme costs. Genencor is now part of DuPont Industrial Biosciences, headquartered in Wilmington, Delaware, while Novozymes North America is based in Franklinton, North Carolina.

Novozymes and Genencor worked with NREL scientists to identify approaches for reducing cellulase costs; those strategies included both decreasing the cost of enzyme production and increasing enzyme efficiency. The research also led to improvements in sugar yields from cellulosic biomass.

The project made tremendous progress in lowering the projected cost of cellulase enzymes. From initial enzyme costs of $4-$5 per gallon of ethanol produced, the team achieved cost reductions that exceeded the subcontract goal of decreasing the enzyme cost by a factor of 10.

This reduction in enzyme cost dramatically reduced the projected cost of ethanol production and represents a major step toward commercializing large-scale biomass-to-ethanol production.

The importance of this research was recognized by R&D Magazine in 2004 with an R&D 100 Award, denoting it as one of the year's 100 most significant innovations.

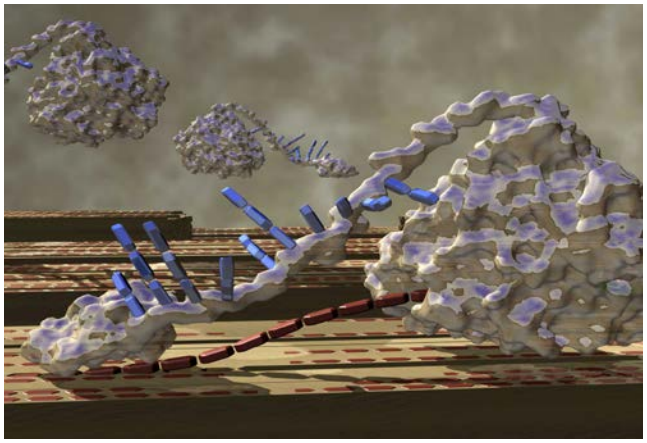
Reducing Enzyme Costs Increases the Market Potential of Biofuels

Cellulosic ethanol prices depend heavily on the cost of the cellulase enzymes used to break down the biomass into fermentable sugars. To reduce these costs, the National Renewable Energy Laboratory (NREL) partnered with two leading enzyme companies, Novozymes and Genencor (now part of DuPont Industrial Biosciences), to engineer new cellulase enzymes that are exceptionally good at breaking down cellulose. The work was funded in part by the Office of Energy Efficiency and Renewable Energy at the U.S. Department of Energy.

Ethanol is produced by releasing the sugars from biomass and then fermenting those sugars into alcohol. Starch-based biomass, such as corn grain, is easily converted to glucose. But breaking down cellulose-based biomass, such as crop residues or forestry residues, is much more difficult. This requires pretreatment with dilute acid or other techniques to make the cellulose vulnerable to enzymatic hydrolysis, which involves using cellulases and other enzymes to convert the cellulose into glucose and other five- and six-carbon sugars. Before the development of advanced cellulases, the process for hydrolyzing cellulose to sugars was very expensive—too expensive to compete with the technology commonly used to break down the starch in corn kernels to sugars, so cellulosic ethanol could not compete with corn-based ethanol.

To hydrolyze the cellulose, NREL and its partners developed a technology that employs a cocktail of predominantly three types of cellulase enzymes: endoglucanases, exoglucanases, and beta-glucosidases. The endoglucanases are thought to break the cellulose chains, creating two new chain ends at each break. Next, the exoglucanases attach to the exposed chain ends and move the cellulose chains away from the crystal structure by a complex process still under study today. The exoglucanase enzymes then proceed to work their way down the chains, liberating cellobiose (a sugar composed of two glucose molecules) as they proceed. Finally, the beta-glucosidases split each cellobiose molecule into two separate glucose molecules, making them available for processing into chemicals or fuels.

This research to engineer cheaper and more efficient cellulases, combined with advances in other aspects of biomass conversion technology, has been critical in progressing cellulosic ethanol technology towards its ultimate goal: becoming cost-competitive with gasoline.



An exoglucanase cellulase enzyme attaches to a cellulose molecule in this computer-generated conceptual image. Successfully reducing the cost of enzymes that break down cellulose to fermentable sugars is key to cutting the cost of producing ethanol and other products from non-edible, cellulosic biomass, such as trees, grasses, and agricultural and forestry residues.

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