innovation

The Spectrum of Clean Energy Innovation

Fundamental Science
Market-Relevant Research
Systems Integration
Testing and Validation
Commercialization
Deployment

Reducing Enzyme Costs Increases Market Potential of Biofuels

Cellulosic ethanol prices depend heavily on the cost of the cellulase enzymes used to break down the cellulosic biomass into fermentable sugars. To reduce these costs, the National Renewable Energy Laboratory (NREL) partnered with two leading enzyme companies, Novozymes and Genencor, to engineer new cellulase enzymes that are exceptionally good at breaking down cellulose.

This innovative research has led to improvements in sugar yields and dramatically reduced ethanol production costs. The importance of this research was recognized in 2004 by an R&D 100 Award for one of the years' most significant innovations.

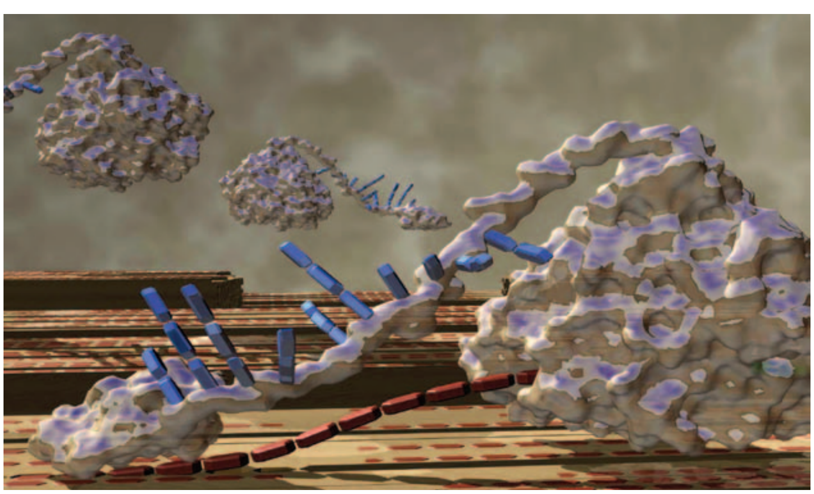
Partnership Speeds a New, Lower Cost Technology to Market

NREL-led technology partnerships generated a way to speed new technologies into the marketplace. In the partnership with Novozymes and Genencor, NREL provided the two companies with access to its innovative biomass characterization, pretreatment, and process integration research.

Using NREL's research as a platform, 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 project made tremendous progress in lowering the projected cost of cellulase enzymes. From initial enzyme costs of $4-$5/gallon, the team demonstrated cost reductions that far exceeded the original subcontract goal of reducing the enzyme cost by a factor of 10.

This reduction in enzyme cost is a major step toward commercializing large-scale biomass-to-ethanol production.



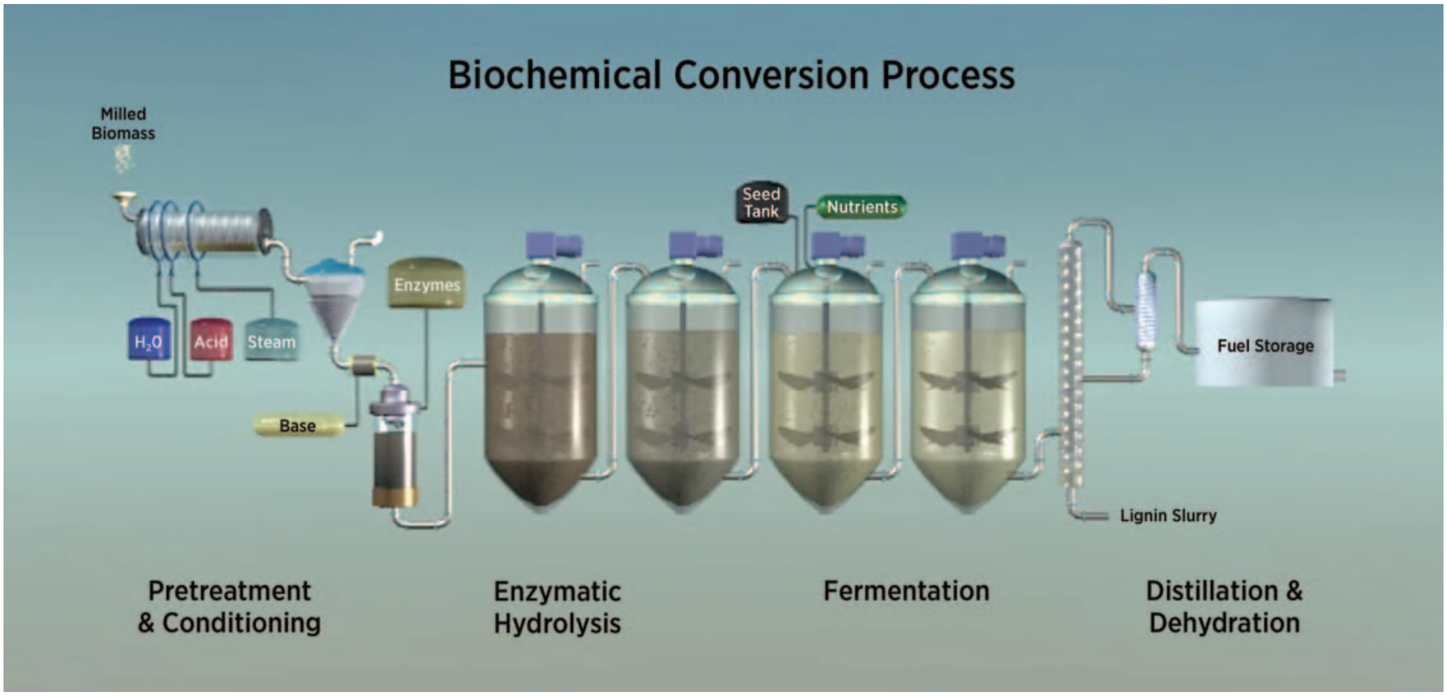
Digital drawing of cellulase enzyme (gray) attached to cellulose (red).
PIX 05014

Through deep technical expertise and an unmatched breadth of capabilities, NREL leads an integrated approach across the spectrum of renewable energy innovation. From scientific discovery to accelerating market deployment, NREL works in partnership with private industry to drive the transformation of our nation's energy systems.

This case study illustrates NREL's innovations and contributions in Fundamental Science through Commercialization.

NATIONAL RENEWABLE ENERGY LABORATORY

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.



A schematic of the biochemical conversion process, from biomass to biofuels.

How the Technology Works

Ethanol is produced by breaking down biomass into sugars and then fermenting those sugars into alcohol. Starch-based biomass, such as corn grain, is easily converted to glucose. But breaking down, or hydrolyzing, cellulose-based biomass, such as crop residues or forestry wastes, is much more difficult. This requires pretreatment with dilute acid or other techniques to make the cellulose available for enzymatic hydrolysis, followed by degradation with cellulase-containing enzyme cocktails to obtain 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.

To hydrolyze the cellulose, NREL and its partners developed a technology that employs a cocktail of predominantly three types of cellulase enzymes: endoglucanase, exoglucanase, and beta-glucosidase.

The endoglucanases are thought to attack the cellulose chains within the crystal structure by breaking the strand via hydrolysis and thereby exposing two new chain ends, one reducing and the other non-reducing chemically. During this hydrolysis process, a molecule of water is consumed each time a glycosidic bond is broken. Next, exoglucanases attach to an exposed chain end and physically pull the cellulose chain away from the crystal structure by a complex process still under study today. The enzyme then proceeds to work its way down the chain, liberating cellobiose (a dimeric sugar composed of two glucose molecules) as it goes. Finally, a beta-glucosidase splits the 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.

National Renewable Energy Laboratory

1617 Cole Boulevard
Golden, Colorado 80401-3305
303-275-3000 • www.nrel.gov

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

NREL/FS-6A4-47572 • June 2010

Printed with a renewable-source ink on paper containing at least 50% wastepaper, including 10% post consumer waste.

innovation