NREL
Advances in Technology at the National Renewable Energy Laboratory
Technology Brief

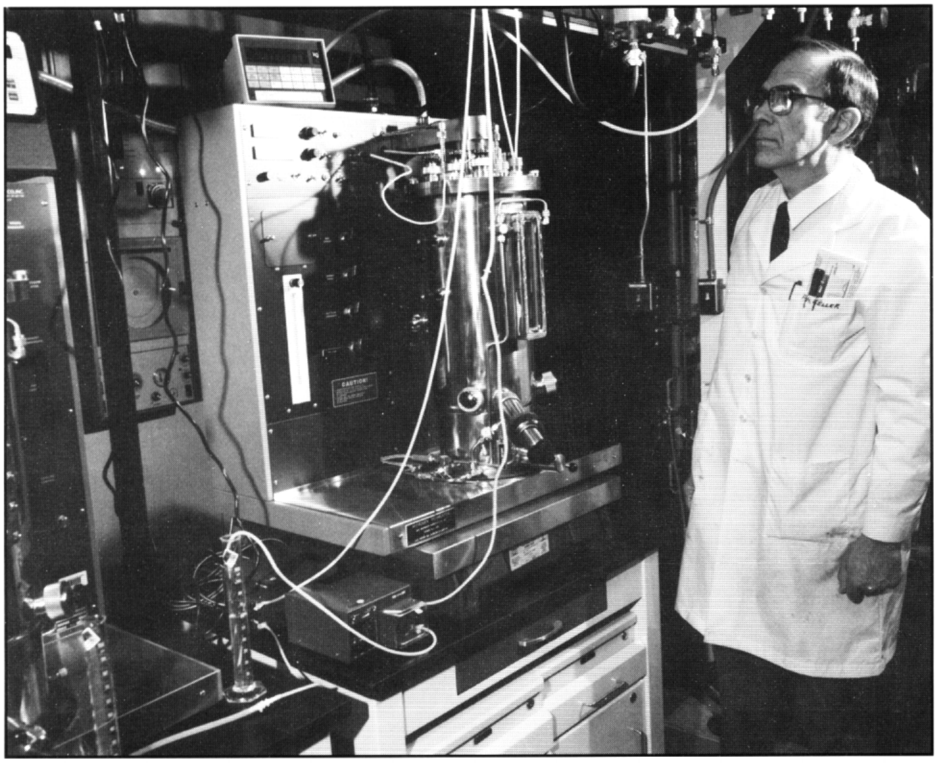
NREL Putting It All Together for Biofuels

Bioprocess Integration: a Critical Step towards Commercialization

What does it take to turn research laboratory discoveries into the new products or industries that will create a better future? In the case of biofuels, which are motor fuels from renewable domestic biomass resources, the U.S. Department of Energy (DOE) is using "bioprocess integration." Many promising biotechnologies could help convert lignocellulosic biomass (the fibrous portion of plant materials or plant wastes) into ethanol or other biofuels. A team of scientists and engineers at DOE's National Renewable Energy Laboratory (NREL) are now integrating several of these technologies at the bench scale just as they would be linked as steps in the commercial production of ethanol from biomass.

Cellulose and hemicellulose make up the bulk of most plant biomass and are not as readily converted to ethanol as are starches and sugars. Several steps are necessary to produce ethanol from cellulosic material (see flow diagram on page 3). Typically the five main process operations are: feedstock milling to reduce the size of the material for processing, thermochemical pretreatment to hydrolyze the hemicellulose to sugars and separate it from the cellulose, fermentation of the sugars derived from hemicellulose to ethanol, hydrolysis of cellulose to glucose and fermentation of that glucose to ethanol, and ethanol recovery.

Industrial and academic researchers can arrange with NREL to use the bioprocess integration systems.



The new process integration laboratories will use equipment like this posttreatment vessel that can be sterilized in place, saving considerable turnaround time between different process operations.

Integrating these steps together will allow the NREL team to answer many questions crucial for designing a successful commercial operation. Which pretreatment processes are most effective on which types of biomass feedstocks? What process variables (temperature, time, and pH) will maximize yields? What effect will chemical or biological by-products from one step have on subsequent steps and on the overall process? Process integration will be particularly valuable in assessing and improving the ability of the planned system to recycle water and other components. Being able to recycle water and nutrients will greatly improve the economics of the process itself and save on wastewater treatment costs. It may also be possible to reuse some of the microorganisms, nutrients, or enzymes.

The Challenge of Lignocellulosic Biomass

Since ancient times, man has taken advantage of the ability of various yeasts to ferment sugars into alcohol. Starches, which are chains of sugars, are fairly easy to break down into sugars that can be fermented. Most of the carbohydrates in plants, however, are more difficult to ferment. These carbohydrates are cellulose and hemicellulose, the fibrous material that provides plants their strength and structure. The links in the chains of sugars in cellulose and hemicellulose are not so easily broken. In addition, cellulose has bonds between chains that give it a crystalline structure. This crystalline cellulose is embedded in hemicellulose and lignin, making breakdown to sugars difficult and posing a challenge for biofuels production.

Although the challenge is great, achieving the ability to use lignocellulose also promises great rewards in biofuels production. Lignocellulosic biofuels feedstocks are more plentiful and less costly to produce than are sugars and starches used for food. If these feedstocks can be economically converted into biofuels, the potential for reducing America's energy dependence and trade deficit with homegrown fuels becomes tremendous. The oxygenated biofuels produced from such resources also cause less air pollution than conventional fuels do and can boost the octane rating. In addition, little, if any, net accumulation of carbon dioxide results from production and use of biofuels, reducing buildup of greenhouse gases.

To meet this challenge, NREL is using enzymes or acids to break up (hydrolyze) the carbohydrate bonds in lignocellulose and convert grasses, fast-growing trees, and wastes into sugars for fermentation into ethanol. NREL is also eager to determine what currently troublesome wastes could be turned into valuable resources as biofuel feedstocks. At the same time, a DOE program being carried out at Oak Ridge National Laboratory is determining whether special energy crops could be grown on marginal lands.

Variety of Techniques Used

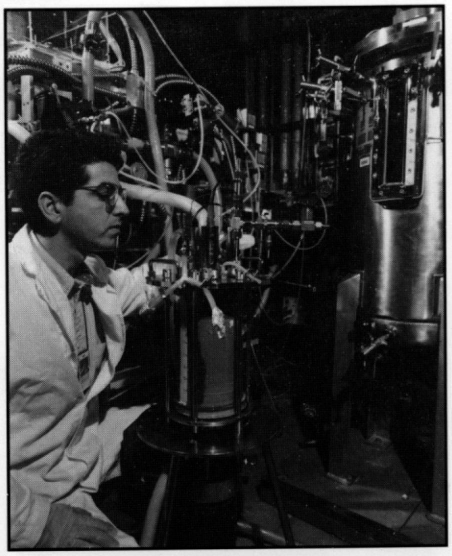
Having linked together an appropriate set of technologies by process integration, the NREL team employs a variety of techniques to analyze the complete biofuels conversion process. At different stages throughout the process, the team analyzes samples to verify concentrations, rates, and yields and to close material balances. Researchers also continuously monitor and experiment with operating conditions to devise process control strategies and optimize performance and cost effectiveness. In addition, they provide data to process engineers who perform process economic evaluations to identify synergies, weak links, and potential valuable by-products, while estimating the total projected cost of production.

New Facility to Enhance Capabilities

As a transition step between laboratory research and pilot-plant development, the results of bioprocess integration will identify the sets of technologies with the greatest potential for commercial production. Those sets of technologies will then be scaled up in a new pilot plant (a process development unit or PDU) being built at NREL. Both the PDU and greatly improved process integration facilities (biofuels bioprocess integration unit or BIU) are part of a new Alternative Fuels Users Facility (AFUF) to open in mid-1994 at NREL's Golden, Colorado, site.

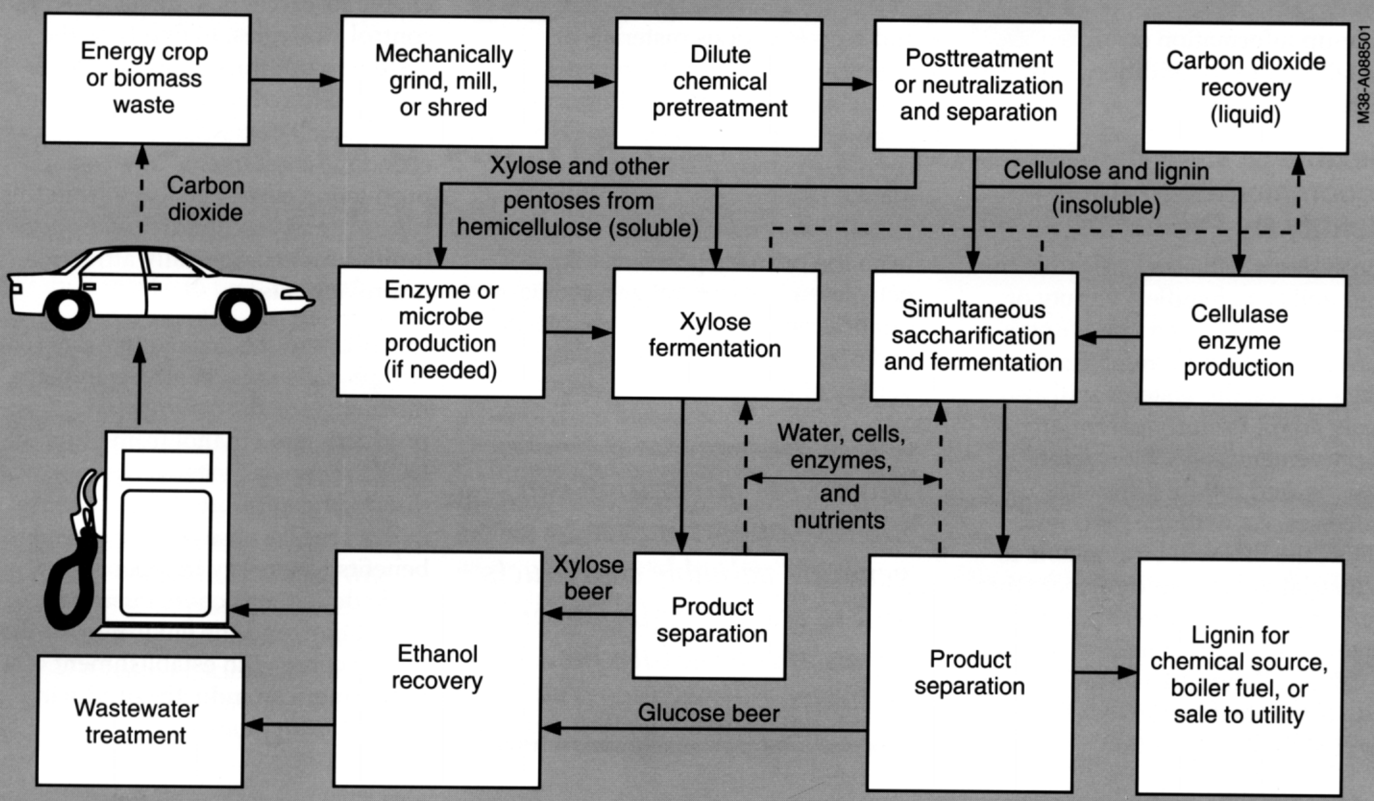
The systems will be modular to facilitate changes. Individual technologies can be moved up to the pilot plant for scale-up information or down to the laboratory for additional applied research information.

The new BIU will include both a "mini" bench-scale process integration system with fermenters about 5 to 10 times the size of laboratory flasks and a "maxi" system with fermenters about 50 times the size of the flasks. The BIU will be able to operate continuously and utilize small pilot-scale, rather than research-type, equipment and processes. The systems will be modular to facilitate



Researcher checks recirculation into one of three simultaneous saccharification and fermentation (SSF) units in interim process integration system. This maze of tubes and wires will be replaced by a custom-designed pretreatment laboratory.

A Typical Process for Producing Ethanol from Biomass



Commercial ethanol-from-biomass processes will likely start with a pretreatment process that mechanically mills the feedstock and uses heat and dilute-acid hydrolysis to break the hemicellulose down into sugars and open up the structure of the plant material. These sugars will be in solution, allowing separation from the still-solid cellulose and lignin. If acid is used, a post-treatment might be necessary to neutralize or detoxify the treated feedstock.

Next, the solid cellulose left will either simultaneously or sequentially be hydrolyzed to glucose sugars by enzymes, and the resulting sugars fermented by yeasts in a series of fermenters to produce ethanol. The sugars derived from the hemicellulose during pretreatment will be similarly treated in a separate series of fermenters, but with special microorganisms capable of acting on xylose and the other sugars derived from hemicellulose.

At the end of each fermentation process, the "beer" containing the ethanol will be removed and distilled to produce the pure ethanol. Water, nutrients, and possibly yeasts, bacteria, or enzyme broth will be recycled back into the process. The residue (lignin, ash, and unreacted raw material) will be used for boiler fuel to drive the process and reduce costs, or possibly for chemical feedstocks.

The NREL bioprocess integration laboratories will start with a process similar to that described above as a reference case. Alternative processes for the various steps can then be tested for their impact on process efficiency and economics. Given all the possible interactions among the process steps and different choices for those steps, bioprocess integration faces a formidable but vital task to test research-proven techniques in a potential production setting and to arrive at an optimal total process.

Although ethanol is the initial target product, use of different organisms could yield different products. One example is isobutanol, which, along with ethanol, can be used to make ethyl tertiary butyl ether (ETBE) for reformulated gasoline. Many other valuable chemicals or fuels could be generated as coproducts or by modifications of the process.

changing processing sequences and conditions. If results so indicate, individual technologies can be moved "up" to the pilot plant for scale-up information or "down" to the laboratory for additional applied research information.

Flexible System Can Accommodate Partners, Identify By-Products

The systems will also be flexible in their ability to handle a variety of feedstocks. Although initial operations will focus on a reference base case process, the systems will also easily adapt to study potential improvements, new bioreactor designs, and totally different processes. As with the PDU and AFUF, the BIU will be available to industrial or academic partners that enter into cooperative research and development agreements (CRADAs) or other collaborative arrangements with NREL to develop technology for commercial operation.

Bioprocess integration can verify interactions between process steps; in addition, it can identify opportunities to recover valuable coproducts and recycle various materials or organisms back into the process. Recycling is particularly important to maintain water balances. Valuable coproducts may prove to be fundamental to a process's economic viability and may be quite different from the primary product. Like petroleum and natural gas, biomass can be turned into chemicals, plastics, and other materials and into a wide variety of fuels.

Bioprocess integration can identify opportunities to generate valuable coproducts and to recycle materials or organisms back into the industrial processes.

The BIU will include instruments for continuous monitoring, data acquisition, and process control. This will enable researchers to develop overall control strategies, to fine-tune the system to optimize rates of production, and to reduce costs. Data from the BIU will be used in technical and economic assessments to estimate production costs. Feedback from this type of analysis can identify opportunities for economically attractive improvements.

The BIU and the capabilities that it will provide are a vital step in the move toward the commercial production of ethanol from biomass. DOE's Biofuels Systems Division directs and supports NREL's efforts in this area because of the tremendous benefits for energy independence, trade deficit reduction, business generation, and the environment that would come with establishment of a new American industry producing ethanol from biomass.

Publications

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