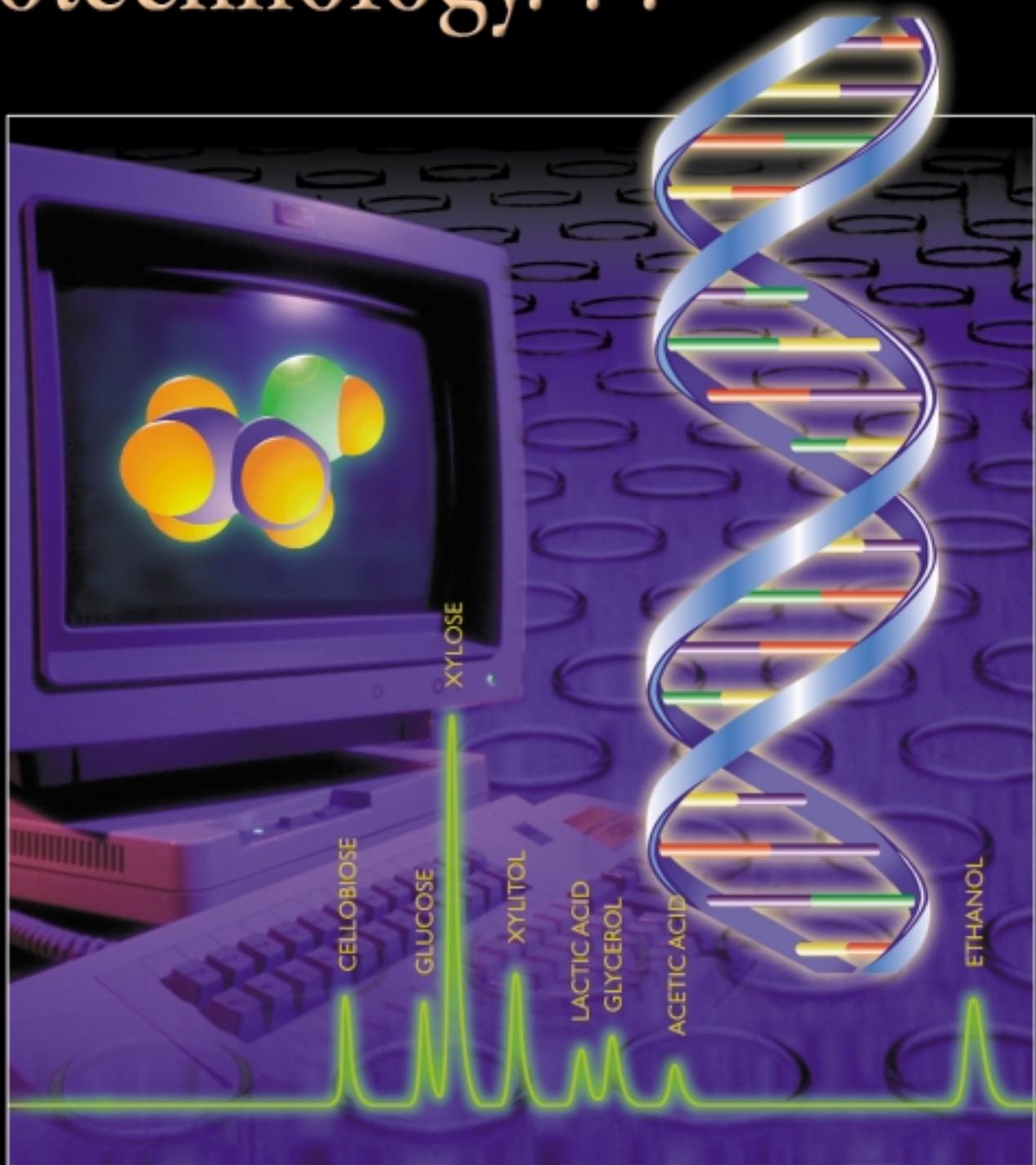


Excellence in Biotechnology. . .



. . .for Renewable Fuels
and Chemicals

Cutting-edge research activities convert biomass to boost fuels and chemicals industries

To develop technology for the cost-effective conversion of biomass to fuels and chemicals, the BCFC is organized into teams that focus on the major biomass conversion unit operations that support the commercialization of biomass conversion technologies.

Biomass Feedstock Pretreatment

Researchers are investigating and developing several technologies for exposing the cellulose in lignocellulosic materials to enzymes that convert the cellulose into sugar. Depending on the feedstock, researchers are applying acid hydrolysis in combination with several recent BCFC-developed pretreatment innovations, including countercurrent processing, two-stage hydrolysis, and shrinking-bed reactor technology. They are also investigating combinations of these technologies with more conventional pretreatment methods, such as steam explosion.

Cellulase Enzyme Development

The BCFC's research on enzyme development focuses on decreasing the cost of the enzyme unit operation in the biomass saccharification process. Researchers are applying recombinant DNA technology to bacteria and fungi to develop improved cellulase enzymes and to determine the most efficient method for producing these enzymes.

Strain Development

Researchers are developing microorganisms that can coferment all the sugars in biomass in order to improve ethanol production economics. They are applying sophisticated metabolic engineering techniques to *Zymomonas mobilis*, *Lactobacillus*, and other bacterial species, while developing a strain that can coferment both xylose and arabinose along with glucose. With industrial partners, researchers are working to develop designer strains for specific feedstocks, feedstreams, and processes.

Process Development and Integration

A team of BCFC researchers focuses on integrating all the unit operations of biomass conversion. With extensive knowledge of the individual unit operations, these researchers focus on linking unit operations together for industrial application and on demonstrating integrated processes at the mini-pilot and pilot scales. They also conduct rigorous bench-scale experimentation to improve specific unit operations within the process.

Process Engineering

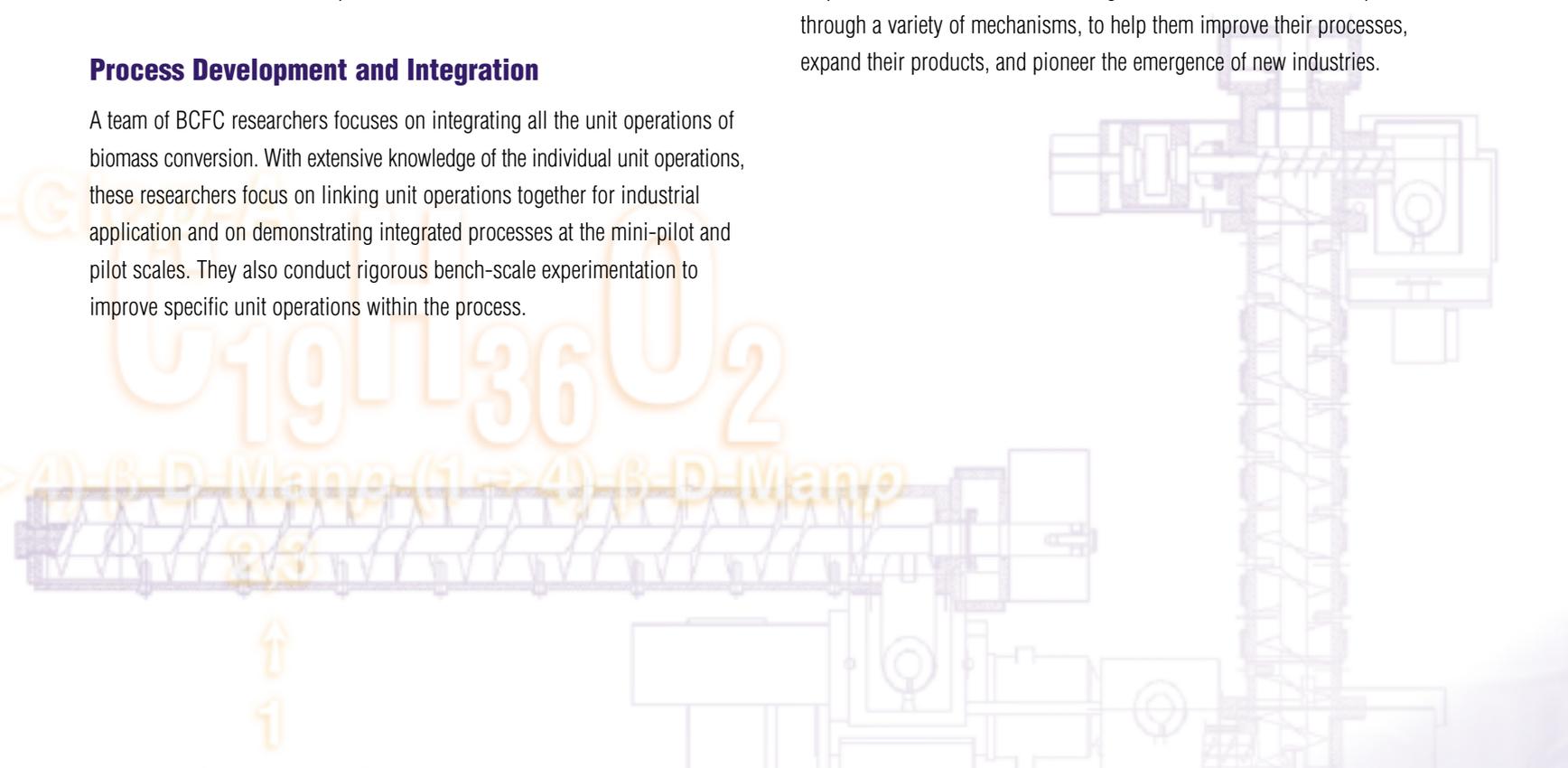
Another team of researchers focuses on bridging the gap between research and full-scale operations, which is critical for the scale-up and commercialization of bioethanol conversion technology. They perform complex process simulations that accurately predict the economics of bioethanol production at industrial scales and thereby determine the feasibility of building and operating a bioethanol plant. Using a rigorous chemical modeling package, which includes mass and energy balances, they evaluate the appropriate size for the process and for specific equipment. They also use a process evaluator tool and gather vendor quotes to accurately determine the cost of equipment.

Life Cycle Analysis

Conducting full life cycle analyses for all of the products of biomass conversion is important for determining environmental and economic feasibility. BCFC analysts use a life cycle inventory modeling package and supporting databases to conduct life cycle analyses. These tools can be applied on a global, regional, local, or project basis. They can also be used to examine the impacts of individual segments of the biomass conversion life cycle, such as different feedstocks, new process technologies, or alternative end-use designs.

Industrial Partnerships

To ensure that our country's investment in the BCFC's research and development reaches the commercial sector, we continue to seek industrial partners who will help commercialize mature technologies. We then work with these partners, through a variety of mechanisms, to help them improve their processes, expand their products, and pioneer the emergence of new industries.



Our Mission

The Biotechnology Center for Fuels and Chemicals leads a national effort, in cooperation with industry, to develop innovative, market-driven biotechnologies for producing fuels and chemicals from renewable resources.

Excellence in biotechnology improves industrial processes and economics

Success in the fuels and chemicals industries is about improving processes and economics. As companies strive to maintain a competitive edge, they search for plentiful and cost-effective feedstocks and state-of-the-art process technologies to improve their processes and expand their range of products.

In the Biotechnology Center for Fuels and Chemicals (BCFC), our successes are about developing advanced biotechnologies to help the U.S. fuels and chemicals industries maintain their competitive edge in domestic and global markets. We focus on using bioprocesses to convert renewable biomass feedstocks into valuable products for these industries. Working with partners in industry, researchers in the BCFC improve processes and products by applying expertise and experience in biotechnology and engineering.

The Biotechnology Center for Fuels and Chemicals is a center of excellence at the National Renewable Energy Laboratory (NREL), a U.S. Department of Energy laboratory dedicated to developing renewable energy and energy efficiency technologies. A focus of the researchers in the BCFC is to help develop, evaluate, and improve technology that converts the cellulosic material in renewable biomass feedstocks into sugars that can then be used to make fuels, chemicals, and other valuable coproducts. A major target of the research effort in the BCFC is converting biomass into fuel ethanol at a cost competitive with gasoline in order to provide the United States with an expanded supply of this renewable, clean-burning, domestically produced transportation fuel.

Since this research began nearly 20 years ago, BCFC breakthroughs have substantially reduced the cost of converting cellulosic biomass into ethanol and other components valuable to industry. Work continues to further reduce the cost and identify industrial partners who will carry these technologies to the commercial sector.



Improved Processes

Expanded Product Lines

New Industries

Reduced Technology Costs

BCFC research advances reduce technology cost, which leads to improved processes, expanded product lines, and new industries.

World-class professionals deliver success and responsiveness to the fuels and chemicals industries

The BCFC's 20 years of success and excellence are built on the expertise and experience of 50 of the world's finest professionals. Of these 50 staff members, about half hold the highest degrees obtainable in their fields. Drawn from academia, private industry, and the government, our experts have more than 500 combined years of experience in biotechnology. Disciplines represented in the BCFC include biochemical engineering, biochemistry, biology, chemical engineering, chemistry, enzymology, microbiology, molecular biology, plant genetics, and process engineering.

The interdisciplinary nature of the BCFC, with its wide range of scientific and engineering talent, offers a breadth and depth of core capabilities unmatched anywhere in the world. This is particularly beneficial to the fuels and chemicals industries because individuals or teams can be rapidly assembled to provide expertise in biotechnology-based systems. This means that when industry comes to us, we have the right people available to provide the specific expertise needed.



Portfolio of Excellence in Biotechnology

Throughout the BCFC's history, our R&D efforts and successes have been guided by the needs of industry and research institutions. We have worked with more than 75 companies and organizations involved with biotechnology for the fuels and chemicals industries. Our research portfolio includes breakthroughs and achievements vital to helping these organizations propel bio-based products into the marketplace.

- **Partnerships with most U.S. commercial biomass-to-ethanol facilities**
- **Three R&D 100 Awards in the 1990s**
- **Four patents issued in 1998, with exclusive opportunities still available**
- **Permit to remove and evaluate a variety of novel microorganisms from Yellowstone Hot Springs**
- **Routinely process high-solids slurries at mini-pilot and pilot scales**
- **Successfully close carbon mass balances**
- **Proven acumen at developing new genetic systems and metabolic pathways for the production of a variety of fuels and chemicals**



The Biotechnology Center for Fuels and Chemicals offers industry access to world-class facilities for improving processes and expanding product lines

A frequent roadblock to industry's expansion of R&D efforts is the capital risk involved in building R&D facilities. To reduce this risk, BCFC has assembled an impressive collection of state-of-the-art facilities dedicated to R&D of fuels and chemicals from renewable biomass materials. Progressing from bench to pilot scale, these facilities are available for companies to use to develop, improve, test, and demonstrate their technologies.

We have designed our facilities for maximum flexibility and usability. Our equipment is uniquely set up for separate and integrated operations. We specialize in running and testing unit operations separately at all scales and in integrating all units in the conversion process. Our facilities offer companies the ability to scale up to provide feasibility of scale as well as to scale down to improve economics of process evaluation.

The BCFC's inventory of facilities has recently grown to include a 1-ton-per-day, 8,000-square-foot pilot plant. Comprising four major components, the pilot plant offers industry consolidated facilities to help test and scale up biomass conversion processes. The process development unit (PDU) includes all operations to convert biomass into fuels and chemicals, including feedstock handling and size reduction, enzyme production, pretreatment, hydrolysis, seed growth, fermentation, distillation, and solid-liquid separation. Major equipment in the PDU includes a Sunds hydrolyzer pretreatment reactor, four 9,000-liter primary fermenters, two 1,450-liter seed fermenters, and a distillation system. A sophisticated data acquisition and control system provides comprehensive process data and minimizes the number of operating personnel. Other facilities within the pilot plant include a bench-scale pretreatment laboratory, a 4-liter steam gun, a newly installed pilot countercurrent pretreatment system, and a pilot-scale ion-exchange and chromatography system.

In addition to the BCFC's vast resources and capabilities, other related technology centers within NREL have expertise and facilities available to augment the BCFC's partnerships and projects with industry.



BCFC's specific experience and expertise:

Biochemistry

- Isolate, purify, characterize, and assay enzymes
- Identify and measure metabolite concentration
- Analyze and model metabolic flux
- Separate, analyze, and convert lipids

Bioprocess Engineering and Modeling

- Model fermentation and pretreatment operations to elucidate the best approaches
- Predict the performance of operations for process evaluation
- Provide formulas for determining the best development paths
- Model and analyze complex processes
- Perform techno-economic and full-cycle analyses

Process Integration, Scale-up and Demonstration

- Develop process integration equipment and methods
- Evaluate and improve process robustness and control
- Scale up processes in the process development unit
- Create and operate novel bioreactors
- Demonstrate improved unit operations at the bench, mini-pilot, and pilot scales

Chemical Analysis

- Analyze composition of solid, liquid, and slurry samples
- Use automated instrumentation for enhanced HPLC/GC methods
- Provide certified analytical service
- Develop unique assays, measurement tools, and correlations

Molecular Biology/Microbiology

- Perform metabolic and protein engineering
- Express genes
- Analyze and sequence DNA
- Isolate and purify genomic and plasmid DNA
- Apply novel DNA introduction and transformation methods
- Introduce new metabolic pathways
- Perform site-directed mutagenesis
- Isolate, characterize, adapt, and evaluate strains
- Develop advanced biocatalysts
- Apply genomics and bioinformatics

BCFC offers companies opportunities to expand success

Application of the BCFC's disciplines, capabilities, activities, and technologies to the fuels and chemicals industries provides opportunities for companies to improve their processes and expand their products.

- For corn ethanol producers, our technology offers advanced enzymes that will saccharify corn fiber and stover into sugars, reducing the volume of waste and producing much greater quantities of ethanol; advanced microbial strains for increased ethanol yield; and improvements in process efficiencies for decreasing operation costs. All of these advances lead to decreased costs and increased profits.
- For next-generation fuel ethanol producers, our technology offers the ability to use biomass feedstocks that are low-cost, abundant, and renewable. They are produced in large quantities from agricultural and forestry activities, and are largely considered to be residue and waste. Our advanced fermentation strains, along with our expertise in integrating process technology, offer the tools with which to launch new companies and a new industry using these residues.
- For chemical-grade ethanol producers and users, these technologies promise access to renewable biomass feedstocks and increased yields and efficiencies.
- For fermentation-based industries searching for low-cost sources of sugars, our pretreatment and enzyme technologies can unlock the sugars stored in abundant low- or no-cost biomass feedstocks, and our microbes can use these sugars to make high-value end products.
- For the chemicals industry, our biotechnology capabilities are one of the keys to developing renewable chemicals and the growth of the industry. These bio-based processes offer new pathways for chemical manufacture.

Partnership opportunities foster industrial success

The BCFC offers a variety of mechanisms through which industrial partners can access our resources. Visit NREL's technology transfer web site, listed in the contact information, to find out about these mechanisms. We also invite you to contact Mark Finkelstein, also listed in the contact information, to explore ways that the BCFC can apply its resources and capabilities to improve your company's success.

BCFC offers stimulating and rewarding career opportunities

To maintain our status as a world leader in applying biotechnology for the production of fuels and chemicals, we are always seeking to enhance our capabilities and raise our level of excellence. We offer a number of professional appointment opportunities including fellowships, sabbaticals, visiting professorships, postdoctorals, internships, and student exchanges. We welcome inquiries from professionals seeking to match their education, skills, and experience with our center's excellence in biotechnology and bioprocessing. To learn about career opportunities, visit our employment opportunities web page, listed in the contact information.



Contact Information

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NREL's Technology Transfer Web Site:
<http://www.nrel.gov/technologytransfer>

NREL's Employment Opportunity Web Page:
<http://www.nrel.gov/lab/hr/jobs.html>

NREL's Biofuels Program Web Site:
<http://www.ott.doe.gov/biofuels>



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