



## Partnering with Industry to Advance Biofuels

For more than 30 years, the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) has been at the leading edge of renewable fuels research and technology advancements to reduce the cost of cellulosic ethanol and develop other cost-competitive alternatives to conventional transportation fuels.

NREL is developing technologies and processes to produce a range of sustainable, energy-dense advanced biofuels that are compatible with our existing transportation fuel infrastructure. As part of that effort, NREL's National Bioenergy Center has entered into more than 90 collaborations in the past five years with companies ranging in size from start-ups to those that appear on *Fortune* magazine's Fortune 100 list.

The new Integrated Biorefinery Research Facility (IBRF) showcases NREL's commitment to collaboration and to meeting the nation's biofuels development and deployment goals. Designed to speed the growth of the biofuels industry, the IBRF is a unique \$33.5 million pilot facility capable of supporting a variety of advanced biofuels projects.

The IBRF is available to industry partners who work with NREL through cooperative research and development, technical, and analytical service agreements. With 27,000 ft<sup>2</sup> of high bay space, the IBRF provides industry partners with the opportunity to operate, test, and develop their own biorefining technology and equipment.

### Research Flexibility

The IBRF offers an unprecedented level of research flexibility. In particular, it can handle a wide range of biomass feedstocks and pretreatment processes. Three parallel pretreatment processing trains allow for the testing of conversion processes using a variety of technologies under a wide range of conditions. The IBRF can handle high concentrations of solids in the

pretreatment and enzymatic hydrolysis steps, a key factor in reducing costs. Bioreactors from 10 L to 9000 L and separation and concentration equipment are housed in the IBRF allowing for biomass conversion processes to be fully integrated.

### Access to Experts

While using the IBRF, industry partners have access to NREL's world-renowned biofuels experts, process equipment, and systems that can be used to develop and evaluate commercial processes for the production of biofuels. In addition, partners have access to NREL's state-of-the-art molecular biology, biochemistry, and biomass compositional analysis laboratories. Advanced biofuels produced in the IBRF can be tested and analyzed in NREL's fuel testing laboratories, and data generated in the IBRF can be incorporated into techno-economic and life cycle analysis models to estimate the feasibility and sustainability of commercial-scale production.

Ultimately, by leveraging the investments DOE has made in the IBRF and NREL, industry partners can develop biofuels conversion processes and technologies faster and enter biofuels markets sooner and more profitably.



The IBRF's new enzymatic hydrolysis reactors can handle high solids – a key factor in reducing conversion costs.

## Pretreatment Capabilities

- **Continuous 1-ton/day horizontal reactor system with the capability for multiple configurations**
  - Residence times of 3-120 minutes
  - Temperature range of 150°-210°C
  - Ability to test and evaluate different pretreatment schemes and catalysts (dilute acid, alkali, or hot water)
  - Hastelloy C-2000 and 316 stainless steel construction
- **Continuous 1-ton/day vertical reactor system**
  - Residence times of 1-45 minutes
  - Temperature range of 150°-200°C
  - Pretreatment schemes (dilute acid, alkali, or hot water)
  - Zirconium construction
- **Continuous 200-kg/day (dry basis) horizontal-screw reactor system**
  - Residence times of 3-30 minutes
  - Temperature range of 130°-200°C
  - Pretreatment schemes (dilute acid, dilute alkali, or steam/liquid hot water)
  - Hastelloy C-2000 construction
- **4-L batch steam gun reactor system**
- **Batch 130-L paddle-type pressure reactor with steam-jacket and direct steam-injection**
- **Batch 1-L mixed reactor with steam injection and ability to handle volatile catalyst**

## Enzymatic Hydrolysis and Fermentation

- **High-solids 4000-L horizontal paddle-type reactors**
  - Operate at total solids loading >20% (w/w)
  - Operate in batch mode with 36-hour turnaround time to achieve semi-continuous processing temperature range 40°-75°C
- **Systems for injecting neutralizing chemicals and enzymes**
- **Bioreactors (continuous or batch/aerobic or anaerobic)**
  - Multiple stirred bioreactor systems from 10-L - 100-L
  - Two 160 L stirred vessels; two 1,500-L stirred vessels; four 9,000-L stirred vessels
  - Feed and support vessels (stirred) ranging in size from 100-L - 9,000-L

## Downstream Processing Equipment

- **10-m-tall by 0.5-m-diameter sieve tray distillation column**
- **Continuous forced recirculation evaporator for concentrating or evaporative operations**
- **Small 1-L solid-bowl high-speed centrifuge (17,000 G) for cell recovery**
- **Continuous sterilizable high-performance decanter (5,000 G) with 100-L/hour capacity**
- **Continuous decanting centrifuge (3,000 G) with 1,200-L/ hour capacity**
- **Semi-automatic perforated basket centrifuge (900 G) with automatic feed, discharge, and washing capability**
- **Semi-continuous pressure belt filter**
- **Continuous sterilizer**
- **Continuous ultrafiltration/reverse-osmosis system**

## Other Capabilities

- **Compositional analysis**
  - Wet chemistry and near-infrared spectroscopy
  - High performance liquid chromatography and spectrometers (infrared, visible, and ultraviolet)
- **Pilot plant monitoring**
  - Real time data acquisition and dedicated mass spectrometer for on-line monitoring of fermentation exhaust gas composition
- **Molecular biology laboratories**
  - Development of enzymes and biocatalysts
    - Strain engineering
    - Proteomics
    - Transcriptomics
    - Metabolomics

For additional information about the IBRF, including inquiries about equipment, capabilities, or partnership opportunities, please contact John Ashworth at 303-384-6858, [john.ashworth@nrel.gov](mailto:john.ashworth@nrel.gov) or Richard Bolin at 303-384-7716, [richard.bolin@nrel.gov](mailto:richard.bolin@nrel.gov).

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NREL/FS-5100-49323 • October 2010

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

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