# Participating Laboratory Capabilities

# DOE National Bioenergy Center

# Strategic Partnerships Workshop

# April 11 – 12, 2001
# Colorado

DOE National Bioenergy Center
Strategic Partnerships Workshop
April 11 – 12, 2001
Sheraton Denver West, Lakewood, Colorado

**Participating Laboratory Capabilities**

**Biobased Products and Bioenergy:**

**Argonne National Laboratory Capabilities and Facilities**

Argonne National Laboratory (ANL) researchers have capabilities ranging from the development of new biocatalysts, engineering cells, developing new separations and purifications technologies, and integrating upstream with downstream processing to reduce cost and increase process efficiency.

### *Catalysis and Separations*

Argonne has significant capabilities in the areas of chemical separations and catalysis:

- ANL has a growing program in biocatalytic or enzymatic conversions with the specific target of biobased chemicals. The program provides an integrated approach to identifying enzymes with specific catalytic activities, developing methods to immobilize active enzymes in robust matrices (including simultaneous separations), and developing engineering solutions to scale up these processes. The Laboratory has identified this program as a Laboratory strategic initiative. The Biocatalysis and Separations Group has extensive experience and capabilities in conducting feasibility studies and process development activities for membrane separation technology applications in chemical production, environmental treatment, and pollution prevention. The Argonne team has considerable experience developing integrated bioprocesses utilizing advanced membrane systems such as electrodialysis or ED (both desalting and water-splitting ED, pervaporation, and other novel membrane materials. Recent work has focused on biocatalytic reactions that integrate bioreactors with membrane separations to run vectorial reactions with enzymes. The group has capabilities in analyzing carbon flows and transport in microbial pathways, and designing these pathways so that they are integrated with downstream processes. Additional capabilities include methods to select and procure specific genes with new characteristics from environmental samples.
- Argonne has strong programs in homogeneous and heterogeneous catalysis with experience working on petrochemical projects. The Laboratory has unique capabilities in catalysis under a wide range of fluidic phases and supports including aqueous, supercritical fluids, micelles, zeolites, and synthetic clays. Phase and support engineering enables catalytic functions to be integrated with separations processes. Argonne is developing and/or analyzing catalytic systems for hydrogenation (and similar reactions), C-H bond activation, selective oxidation, polymerization and depolymerization, etc. These resources have been employed to produce hydrocarbon-based products from petrochemical feedstocks and can now provide a unique opportunity for catalytic systems design for selective conversions of biological starting materials into chemical products.
- Examples of key projects related to biobased products include:

    Process to develop a microbial pathway for Vitamin C partnered with Genencor, Eastman Chemical, Electrosynthesis, and Microgenomics. Argonne's major contributions included pathway analysis, pathway modification, methods to obtain specific genes from environmental samples, and enzyme stabilization. Construction of a plant based on the process has been announced by the industrial partners.

    Process to develop lactate esters utilizing advanced membrane technology has led to opportunities to produce ethyl lactate as a 'green' solvent. Argonne developed novel double electrodialysis (desalting and water-splitting) to recycle acid/base without producing a byproduct salt. The Laboratory also developed a pervaporation-assisted esterification method to increase the efficiency of the esterification reaction. It piloted the acid-ester process to purified ethyl lactate and demonstrated the technical feasibility of a direct esterification method (though the latter did not yet achieve commercial targets). Argonne supported utilization work on testing ethyl lactate/soy methyl ester blends. It partnered with Vertec BioSolvents in collaboration with ADM. The process has won numerous awards including the President's Green Chemistry Challenge, the *Discover* Magazine Award for Technology Innovation, the Energy 100/Energy 23/Bright Light Awards, the DOE/OIT Technology of the Year (Finalist), and the Federal Laboratory Consortium Award for Technology Transfer.

Development of mixed fermentation of sugars to produce lactate esters. This is a partnership with the University of California-Davis along with industrial partners and other groups.

Other projects include the fermentation, production, and separation of succinic acid; the development of electrodeionization technology to replace costly ion exchange processes in corn processing; advanced membrane technology for hydrogen peroxide production; and conversion of lignocellulosic feedstock to produce ethyl lactate.

***Characterization and Analytical Capabilities and User Facilities***

- Argonne is the center for some of the most powerful characterization techniques and analytical laboratories in the world. The Advanced Photon Source (APS) provides the most brilliant x-ray source and the opportunity to characterize the structure and composition of natural and synthetic materials. The APS is the premier facility for determining protein crystal structures. In addition, the APS provides the tools for monitoring composition, localization, and redox state of specific chemical elements in specific biomolecules, biological tissues, and synthetic materials. With emerging capabilities in nanoscience, ANL should be able to image elemental distributions down to the subcellular level.
- Argonne has several other major user facilities with a strong potential for impacting the characterization of materials. These include the Intense Pulsed Neutron Source (IPNS) for characterization of multiphasic materials and the Electron Microscopy Center. The biobased products project team, for example, has used the Center to definitively characterize new membrane materials used to develop innovative biobased separations technologies. The Chemistry Division has used IPNS to characterize protein structures and properties of biomimetic membranes.
- Several unique capabilities in magnetic resonance (NMR and EPR) are available at Argonne. An advanced, high-pressure NMR laboratory that Argonne developed enables characterization catalysis kinetics and thermochemistry under industrial conditions. In addition, Argonne has unique solid-state NMR capabilities for monitoring processing in complex heterogeneous materials. Argonne uses EPR to monitor redox processes in reactions critical for bioconversions.
- Argonne is a leading center in spectroscopic characterization of chemical and biochemical processes. These capabilities include laser laboratories and optical spectroscopic techniques for monitoring reaction mechanisms, as well as mass spectrometry for high-resolution analysis of complex biological and chemical systems.
- ANL has upstream pathway engineering capabilities and downstream separations and processing capabilities that range from fundamental through small pilot-scale for chemical and biochemical projects. A unique capability of the biobased chemicals team is to analyze

pathways, including carbon flow, cofactors, transport, etc.; develop modified pathways that increase productivity; and integrate the pathway engineering with innovative downstream separations. These capabilities include liquid and gas chromatography, supercritical extraction, and membrane technology.

***Genomics and Biological Capabilities***

- Other important capabilities include structural genomics, proteomics, and biochip manufacture and application. All of these will be useful for the next generations of biobased technology development.
- Bioinformatics – Argonne has developed unique and widely used systems for genetic sequence analysis, metabolic reconstruction, and comparison of metabolic subsystems, together with unique interactive databases on proteins, enzymes, and metabolic pathways. These tools include the following:

    EMP (Enzymes and Metabolic Pathways) is the largest publicly available database of such pathways in the world. (It is a collaborative effort between Argonne and the Russian Academy of Sciences' Institute of Theoretical Biophysics.)

    WIT2 is a well-known, widely used integrated environment to support genetic sequencing and comparative analysis of sequenced genomes and permit metabolic reconstructions from sequenced data. Data from 38 completely or almost completely sequenced genomes are available through WIT2, which gives researchers access to thoroughly annotated genes. ANL would like to expand this database to include genomes of interest to the biobased production community.

    PUMA2 (Phylogeny, Metabolism, Alignments) is an environment for comparative analysis of metabolic subsystems, based on a collection of metabolic modules that are connected to sequence data. This new model is under development (as an improvement over the widely used PUMA model developed by Argonne) and is useful for designing metabolic pathways. It could be expanded to pathways of interest to biobased products. This includes the development of a phenotypic database with an initial emphasis on organisms involved in bioremediation and medicine, though expansion to include organisms of agricultural interest would be possible. This phenotype database is being developed in collaboration with PNNL.

    PatScan (Pattern Scanning) is a publicly accessible web application that researchers can employ to look for user-defined patterns in nucleotide and protein sequences, which are checked against the major protein sequence databases.

***Systems Modeling***

Argonne has significant expertise in systems modeling, cradle-to-grave, and life-cycle analysis of cost, environmental, energy, risk, and socioeconomic factors of a technology and its utilization. While not yet applied to biobased products applications, the Argonne groups do considerable work on energy and defense –related issues state-of-the-art tools. Analyses typically include three basic components:

- Inventory – where inputs (e.g., energy, raw materials) and outputs (e.g., wastes, co-products) are quantified;

- Impact Assessment – where the items identified in the Inventory Phase are characterized in terms of cost, environmental effects, human health and safety, and other pertinent parameters; and
- Improvement Assessment – This often entails a systematic evaluation to identify and characterize opportunities for improving the process or product through greater efficiency, reduced environmental impacts, etc. Alternative options may be evaluated in this portion of the analysis.

***Additional Areas of Expertise***

Also available at Argonne are capabilities in waste characterization, evaluation and reuse in agricultural contexts, and industrial applications. These capabilities rely on traditional and ad hoc analytical and modeling tools and a highly qualified staff of economists, sociologists, policy analysts, system analysts, environmental engineers and scientists, and modelers.

Expertise ranges from the identification of industrial technologies to improve process efficiency, impact of new technologies on macroeconomics and employment, cost and performance of new technologies, and analysis of potential markets for new technologies. Expertise is also available in logistics and mobility

**Meteorological Research**

Argonne's Meteorological Section has a number of studies, most notably the DOE Atmospheric Radiation Measurement Program (ARM) that at the core addresses improvements in weather forecasting. Such studies address the fundamental meteorological processes that make up the various weather conditions. Clearly, a better understanding of these processes could be key to developing approaches that can "neutralize the impact of weather conditions on production."

**Terrestrial Ecology**

Argonne's Terrestrial Ecology Group has a number of ongoing research projects that could contribute to the Biobased Products and Bioenergy research program. Basic research studies understanding the role of micorrihizal fungi in facilitating plant nutrient availability are key to improving agronomy practices. The studies focused on Nitrogen are particularly valuable to optimizing nitrogenous fertilizers. In addition, studies within ANL's Environmental Molecular Science Group, wherein reactions within individual cells (e.g., a bacterium or a plant cell) can be observed in real time at the atomic level are likely to be relevant.

**Partnering**

Collaborators in biobased products and related areas include:

- ADM
- A.E. Staley
- Monsanto
- Eastman Chemical
- Genencor
- Electrosynthesis
- Microgenomics
- Vertec BioSolvents
- Unitel
- NTEC ED Sep
- ProSep
- Sulzer Chemtech
- CT Chemical
- UOP
- Tokyama
- Celanese
- Cognis
- GE
- Collins Pine
- Applied Carbochemical, Inc
- Integrated Genomics
- Motorola
- Packard
- Agilent
- Nalco Exxon
- UC-Davis
- Iowa State
- University of Illinois
- Purdue
- Michigan State
- DOE Ames
- USDA NAURC Lab

**Contact:** For more information, contact Jim Frank, Director of Biotechnology Applications (630/252-7693), Jfrank@anl.gov, or refer to Argonne's Biotechnology website (www.ipd.anl.gov/biotech/index.htm).

**Brookhaven National Laboratory Capabilities**
**In Biofuels, Bioenergy, and Bioprocessing Research**

## 1.0 Research Interests

Brookhaven National Laboratory (BNL) has a broad range of capabilities in biofuels, bioenergy, and bioprocessing research which is performed by several groups at the Laboratory. In the Building Equipment Technology group, research into the use of biodiesel in residential and commercial heating equipment is being conducted under the sponsorship of the Department of Energy (DoE) and of the New York State Energy Research and Development Authority (NYSERDA). This research is built on the group's extensive and highly successful research and development work in residential heating equipment for over twenty years.

In the Advanced Fuels Group, research and development into the bioprocessing of fossil fuels is being carried out. Fossil fuels are treated with meso to thermophilic bacteria under high pressure. The treatment may upgrade the fuels through processes including desulfurization, denitrogenation, and redistribution of hydrocarbons. In addition to upgrading of heavy oils, the processes are applicable to enhance oil recovery in the field and in bioremediation of oil spills.

The Biology Department is conducting research with the objective of using plants as "Green Factories" to produce specific renewable resources. Advances in genetic engineering have resulted in routine methods for the introduction of genes into crop plants. Previous efforts have focused on the transfer of existing genes into plants to tailor plant storage compounds. A key element of future efforts will be directed towards engineering enzymes with novel specifities and/or the ability to introduce a particular functionality. This will free metabolic engineers from the constraints imposed by the existing variation of natural enzymes and will present a major step towards the engineering of desired storage compounds.

## 2.0 Unique Facilities

The following gives an overview of some of the facilities in the division that are unique and/or have demonstrated their utility in biofuels and bioprocessing reseach.

### 2.1 Oilheat Research Laboratory

BNL maintains a well-equipped test laboratory for combustion research. The facility contains four test stations, of which three are installed for hydronic (hot water) boiler testing and one is for warm air furnace evaluations. These test stations serve to evaluate heating equipment efficiencies and thermal performance using heat and mass flow measurement techniques. Stack gases such as CO, C02, 02, and NOx can be continuously sampled and measured using on-line instrumentation both under steady state and transient operations. Gas analyzers have been assembled in a console unit equipped with sample handling components for pre-conditioning and recorded using data loggers. Smoke, both in steady state and transient operation, is measured manually.

A desktop microcomputer system installed on- line provides automated control, and facilitates data acquisition and analysis. The computer receives the analog signals from the various flow and temperature transducers and calculates heating and efficiency values based on thermodynamic laws. Software has also been developed to operate the equipment in both steady-state (continuous) and cyclic (intermittent) modes.
In addition, facilities are also available for performing atomization studies using a laser spray analyzer to measure fuel drop size. This system uses the radial distribution of diffracted light to obtain the spray drop size distribution. A dedicated computer converts the light distribution to a drop size distribution in minutes, providing rapid and accurate data handling. A Laser Doppler Velocimeter is being added to measure air velocities rapidly and accurately.

A modern, commercial Computational Fluid Dynamics software has been implemented and is being increasingly used in modeling burners and combustors.
The OilHeat Research Laboratory offers opportunities for and has performed collaborative work with the private sector.

### 2.2 Bioprocessing Laboratory

BNL's Bioprocessing Laboratory has a wide range of analytical instruments including mass spectrometer, GC-MSn, LC-MSn and ICP-MS. It has also spectroscopy capabilities including UV-Vis, IR and ESR. Microbiology laboratory facilities are also available. These facilities have been used in past and current bioprocessing research.

**Contacts**


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|---|---|
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| Bioprocessing: | Mow Lin, Mow@bnl.gov |
| Oilheat Lab: | Roger McDonald, McDonald@bnl.gov |
| Biology Department: | Carl Anderson, cwa@bnl.gov |

## Idaho National Engineering & Environmental Laboratory Capabilities
## In
## Bioenergy Research

INEEL has performed R&D for energy and environmental applications, including bioconversion of renewable resources into fuels and chemicals, for over twenty years. Complete descriptions of the wide ranging technology development work along with publications can be found on the INEEL website (http:www.inel.gov). A summary of this information is given below.

**Key Contacts:** Tom Foust, 208-526-0147, foustd@inel.gov
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### Research Area Descriptions

*Bioprocess/Processing Systems* **-** Bioprocessing/Processing R&D at INEEL includes both fundamental and applied research on pertinent biological and non-biological systems. Specialized bioprocessing systems have been developed to demonstration levels for a wide range of energy and environmental problems. These systems include novel bioreactor concepts and the use of biocatalytic and chemical catalytic agents as critical components. Applications include:

- conversion of renewable resources to chemical building blocks for materials production, e.g., plastics, lubricants, soil amendments, etc.
- biofilters/bioreactors for aqueous and nonaqueous vapors processing
- extremophile enzyme characterization and formulation for biological catalysis to produce commodity and specialty chemicals
- decision support systems for agriculture to optimize fertilization and watering processes
- microbial strain development for energy and environmental applications
- multiphase continuous reactors using immobilized biocatalysts,
- extreme bioprocessing for high temperature, high pressure applications
- product separation technology based on advanced membranes and fractal chromatography

*Applied Biological and Agricultural Technology* **-** Applied biotechnology development at INEEL focuses on biological systems to solve, in collaboration with industry, energy and environmental problems. Bioconversion processes that utilize intact microbes, cell free extracts, and non-biological catalytic models of enzymes are integrated for specific problem solutions. Fundamental improvements lead to applied solutions and with intellectual property implications. Areas of biotechnology and bioenergy research which currently include complimentary INEEL capabilities are:

- Application of auto steering software and 'hitch-pin' sensor characterization for biomass production and harvesting applications with energy conservation benefits. This program also develops remote sensing tools for variable-rate irrigation and/or chemigation in crop production.
- Enhanced energy extraction from black liquor residuals in pulp and paper operations range through biofilm processing to innovative spray nozzle designs.
- Directed evolution and screening for improved enzymes from extremophiles gathered from such diverse environments as Yellowstone thermal pools, Pacific Ocean trenches, and the Arctic are completed for biomass conversion, fossil fuels modification, and controlled materials surface changes.

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**Unique Facilities**

*Bioprocessing Meso-Scale Facility and Associated Laboratories* - The INEEL Bioprocessing Meso-Scale Research Facility is available to INEEL researchers, visiting researchers, and industrial partners. This resource, open to university, national laboratory, and industrial scientists and engineers, is complimented by a large suite of laboratories equipped with a wide range of analytical instrumentation.

Many of this laboratory facilities are contained within the Botechnology Department which is housed in seven laboratories with a total of 7500 sq. ft. at the INEEL Research Center in the city of Idaho Falls. An additional 4500 sq. ft. of space for pilot scale testing and development is available in two scale-up areas. These laboratories contain all essential microbiological, molecular biological, analytical equipment and instrumentation. Numerous stereo and compound microscopes, epifluorescence microscopes (Nikon Eclipse E600 and Zeiss Axiomat), incubators (from 10-90°C), gas chromatographs, HPLC/photodiode array detection, AA, superspeed centrifuges, a Beckman ultracentrifuge, ultra-low temperature freezers, X-ray fluorescence instrumentation, walk-in cold rooms and controlled temperature rooms are distributed throughout the Department. Automated DNA synthesis (Cruachem PS250) and sequencing apparatus (ABI Prism 3700 DNA analyzer for high-throughput sequencing, and a Li-Cor 4000L), a capillary electrophoresis instrument (Bio-Rad CE3000), 30 L fermentor (New Brunswick Scientific Bioflo 4500), rapid protein purification (Applied Biosystems Vision Workstation), and several DNA thermal cyclers, including a real-time instrument (Idaho Technology RAPID) are available. There is also equipment available for near-surface analysis, including atomic force microscopy, electrochemistry (EG&G multiplexed potentiostat, SRET), environmental scanning electron microscopy (Philips ESEM), confocal scanning laser microscopy (Nikon PCM 2000), mass spectrometry, NMR, ICP, SEM/STEM, Auger and ESCA spectroscopy, and a wide array of techniques for nondestructive analysis of materials. In addition to internal investigators, external researchers utilize these facilities independently or in collaboration with INEEL staff for both short and long periods of time.

In addition to the above described facilities, there are a number of controlled field test plots and greenhouses for studies employing biocatalysts and plants for *in situ* studies, e.g., high energy materials degradation, plant nutrient and water uptake, growth trials of genetically engineered plant strains. These facilities are equipped to allow researchers to focus on a wide range of energy and environment problems.

**Expertise**

INEEL has more than 50 permanent staff members together with 25 or more visiting academic staff, work directly in areas ranging through biocatalysis, microbiology, plant science and botany, and biochemical engineering. Complimentary expertise in such areas as electronics, computer software and hardware, and mechanical engineering is drawn from sister organizations at the Lab. Researchers work on a variety of joint projects with other national laboratories as well as industrial, and academic partners for DOE-relevant applications of biotechnology. These staff have numerous peer-reviewed journal articles and patents, plus such national and international recognition as R&D 100 Awards in diverse subject areas including molecular biology, microbiology, biochemical engineering, chemical engineering and mechanical engineering. The INEEL is a supporting sponsor of the ongoing annual *Symposium on Biotechnology for Fuels and Chemicals Series.*

In addition, the INEEL has a long record of technology transfer and collaborative research. Cooperative Research and Development Agreements (CRADAs) are the basis for several research programs. Example completed and ongoing programs cover production of chemicals from biomass to valving for field production of biomass for food/feed/fiber/energy.

**INEEL Capabilities in Areas Relevant to Bioenergy and Bioproducts:**

*Enhancement of Agricultural Residues*- Projects are underway to use an on-farm, white-rot fungi based process to increase the percentage of cellulose in waste wheat straw. This refined straw will then be used as a feedstock for a variety of cellulose requiring processes. Additional work is being performed to decrease concurrently decrease the silica content of wheat straw. This whole crop utilization approach not only brings added value to growers, but also helps alleviate environmental concerns such as the widespread straw burning that takes place throughout the intermountain west following each growing season.

*Extremophile-Based Biocatalysis*- INEEL scientists and engineers have decades of experience in using extremphilic microorganisms as robust catalysts for a variety of industrially important transformations. This work has encompassed numerous aspects of extremophile microbiology and biochemistry including extremophile molecular biology and genetics with emphasis on whole genome sequencing and molecular breeding as well as extremophile- based enzymology. Numerous projects involving extremophilic biocatalysis are currently ongoing, including a project to produce plastics monomers using genetically engineered extremophilic bacteria.

*Intelligent Control of Bioreactors*- The INEEL has a long standing interest in the development of learning-based intelligent control bioreactor systems. These systems use novel computer software to allow control of complex, multivariable bioreactions that would be extremely difficult, if not impossible to control using traditional "trial and error" techniques.

*Molecular Biology*- A long standing expertise in procaryotic molecular biology exists at the INEEL. This expertise encompasses essentially all common molecular biology techniques and is currently focusing on whole genome sequencing using a high through put sequencer, and the development of engineered enzymes using molecular breeding and directed evolution techniques. This capability has been directed towards a number of applied problems including the engineering of bacteria to produce plastics monomers and bioadhesive agents.

*Microbiology*- Strengths exist in traditional microbiology, microbial ecology, and microbial physiology. INEEL microbiologists are adept at the cultivation and characterization of novel, difficult-to-grow microorganisms, and regularly work with colleagues in molecular biology to increase the physiological capabilities of these organisms for industrially or environmentally relevant purposes.

*Separations*- Advance membrane separations has been an area of concentration at the INEEL for over the past decade. Of particular interest to bioenergy applications is work being done on polyphosphazine membranes that are especially adaptable to the concentration of end-products diluted in biological media.

**Los Alamos**
**National Laboratory**

# Bioscience Division

***Innovation for Health and Security***

Serving the nation's needs in health and national security, Bioscience Division fosters research at the interface of biology, chemistry, physics, and computational biology. The Division provides a multidisciplinary mix of science capabilities that includes biologically inspired materials and chemistry, computational biology, environmental biology, genomics, measurement science and diagnostics, medical applications, molecular cell biology, molecular synthesis and structural biology. These capabilities are focused in the strategic thrust areas of biothreat reduction, functional genomics, structural genomics, complex biosystems modeling, biochemical diversity, and biomedical sensors. The Center for Human Genome Studies also resides in Bioscience Division.

**Integrating Themes in Bioscience Division Thrusts**
- Understanding biological diversity
- Harnessing biological diversity for technological applications
- Understanding the impact of biological and environmental agents on human health
- Reducing the threat from biological and environmental agents

# CORE SCIENCE RESEARCH

### 1) *Biologically Inspired Materials and Chemistry*

This combination of capabilities is aimed at understanding the characteristic properties of cell membranes, cells, tissues and biominerals, such as self-organization, hierarchy, complexity, adaptability, self-repair. The ultimate realization of the ability to mimic living functions will lead to entirely new classes of biologically inspired materials suitable for a host of practical applications in biotechnology, nanotechnology and materials science.

### 2) *Computational Biology*

The Human Genome project has developed powerful capabilities in bioinformatics, that have been applied to several areas of specialization: microbial informatics (unique data bases for HIV, influenza, and sexually transmitted diseases), gene expression (host pathogen interactions), and informatics tools for deciphering the sequence data from the human genome. Advanced statistical analysis techniques and massively parallel processing capabilities are being used for a variety of problems. Modeling tools are being developed for predicting protein structure and function.

### 3) *Environmental Biology*

Responding to requirements in national health security, Los Alamos has developed expertise in microbial biology related to genomics. These include phylogenetics of pathogenic microbes, the study of non-culturable microbes using molecular techniques, molecular characterization of biological threat agents, development of molecular methods for rapid detection and characterization of species, and methods to rapidly identify virulence genes. Molecular methods have been developed for the detection of drug-resistance and genetic manipulation of threat pathogens. AFLP data is used to identify DNA sequences that vary among different strains of the same species, and information from low-pass genomic sequencing to develop species-specific PCR primers to detect pathogens in environmental samples.

### 4) *Genomics*

Bioscience Division has extensive sequencing capabilities that have been ramped up to increase production and decrease costs in response to the requirements of the Joint Genome Institute (JGI). The Los Alamos group has become expert in several aspects of DNA sequencing: source DNA purification, subclone library construction, template DNA purification and labeling, and gel electrophoresis. Robust mapping protocols involving pooled hybridizations and PCR screening of pooled genomic libraries supply a majority of the mapped clones for the JGI. An integrated informatics system encompasses the entire range of sequence-related processes and robust set of tools has been developed for generating order and orientation from draft sequence. Software and protocols are being adapted to support sequencing, assembly and annotation problems necessary for functional and comparative genomics. An extensive set of capabilities has been developed to understand the functions and interactions between all genes and gene products in a cell: cDNA sequencing, microarray technology, phage display, protein expression, mass spectrometry, bioinformatics. Electro-spray and MALDI-TOF mass spectroscopy instruments have recently come on line for functional analysis of proteins. A very rapid flow cytometry method for typing thousands of Single Nucleotide Polymorphisms (SNPs) per day that is amenable to large scale studies of human genome diversity has been achieved.

### 5) *Measurement Science & Diagnostics*

Ready access to multidisciplinary technologies has proven invaluable for generating and disseminating technologies that build on measurement science and diagnostics. Bioscience Division has capabilities in spectroscopy (vibrational, mass, NMR, UV-Vis, luminescence, single molecule methods and EPR) and scattering measurements (visible light, X-rays and neutrons); flow-based analysis ("cytometric" techniques, such as the National Flow Cytometry Resource); imaging (vibrational and fluorescence imaging, scanning tunnelling and atomic force microscopes); and time resolution tools that span 17 orders of magnitude to study the biodynamics of protein folding.

### 6) *Medical Applications*

Multiple disciplines are applied to the development of new analytical technologies for biomedical research, disease detection, health monitoring and bio-threat detection. They include methods for labeling tumor localizing peptides with radionuclides; tumor specific antigens for the early detection of breast cancer; light scattering methods for detecting breast tumor margins and diagnosing lymph nodes *in vivo* and for assessing chemotherapy and photodynamic therapy drug concentrations; analysis of single nucleotide polymorphisms (SNP's) to identify disease-related genes and diagnose diseases; and the development of non-invasive tools for the measurement of intracranial and intraocular pressure.

### 7) *Molecular Cell Biology*

The natural evolution of biological research in a nuclear weapons laboratory has led to a primary interest in cellular response to radiation and other damaging agents on human health and the downstream effects of that response. Understanding the mechanistic basis for recognition and resolution of DNA damage and repair is a primary capability, providing new insights into cell death and tumorgenesis. The importance of the tissue environment is being explored with 3-dimensional multicellular spheroid models that mimic the tumor microenvironment

### 8) *Molecular Synthesis*

Los Alamos has been at the center of isotope chemistries for more than 22 years. The NIH Stable Isotope Resource (SIR) at Los Alamos (B1-S) has played a pivotal role in the development of new, efficient methods to label biomolecules. In addition, there are new developments in the design and synthesis of linker molecules for tethering molecular recognition moieties onto biomimetic surfaces, fluorescent probe labeled proteins or ligands, polypeptides, and self-assembly membrane-forming components; and biomimetic interfaces that are essential components of biosensors, bioelectronics and diagnostic devices

### 9) *Structural Biology*

The Division has developed significant capabilities in high throughput protein production and structure solution and routinely carry out NMR analysis of proteins, for both structure and dynamics. In addition, the Los Alamos Stable Isotope Resource develops and supplies labeled compounds for structural biology applications. Substantial capabilities exist for studying the internal dynamics of proteins and nucleic acids using both NMR analysis and laser and time-resolved spectroscopies. Neutron diffraction facilities and small-angle scattering capabilities when coupled with modeling tools provide the basis for developing 3-D structures of proteins. Capabilities in vibrational spectromicroscopic imaging of cells and tissues allows identification of molecular structures and functional states in vivo. Theoretical frameworks for analysis of the fundamental properties of water and its interactions with biomolecules have been developed, as well as extensive modeling tools for nucleic acids and proteins. This integration of experiment, theory and modeling is a powerful combination for the future challenges in structural biology.

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**National Renewable Energy Laboratory Capabilities**
**Biotechnology Division for Fuels and Chemicals**
**National Bioenergy Center**

The scientists and engineers at NREL in the Biotechnology Division for Fuels and Chemicals work to develop innovative, market-driven biotechnologies for producing fuels and chemicals from renewable resources. These efforts are conducted in close cooperation with industry, in particular with the nascent bioethanol industry, which relies upon the staff of the Biotechnology Division to evaluate existing technology and to develop new technologies to support commercialization. The U.S Department of Energy's (DOE's) Biofuels Program largely resides at NREL in the Biotechnology Division. For more information visit the following web sites: Biotechnology Division at http://www.nrel.gov/biotechnology/ or the Biofuels Program at http://www.ott.doe.gov/biofuels/. Key Contact: Mark Finkelstein - Division Director, (303) 384-7755, mark_finkelstein@nrel.gov

## Core Capabilities

To develop cost-effective technology for the conversion of biomass to fuels and chemicals, the Biotechnology Division has developed strong capabilities in each facet of biomass conversion technology.

### Biomass Characterization

For information on ASTM and NREL standard wet chemical methods see the web site at http://www.ott.doe.gov/biofuels/properties_database.html. See “Capabilities in Biomass Analysis and Characterization” page for more detailed information.
Contact: Bonnie Hames, (303) 384-6345, bonnie_hames@nrel.gov

### Biomass Feedstock Pretreatment

Researchers are investigating and developing several technologies for exposing the cellulose in lignocellulosic materials so that enzymes can convert the cellulose into sugar. Depending on the feedstock, researchers are applying acid hydrolysis in combination with several recently 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. Pretreatment equipment available ranges from a continuous reactor with a capacity of one dry ton per day of biomass through small bench scale batch reactors. Contact: Richard Elander, (303) 384-6841, richard_elander@nrel.gov

### Cellulase Enzyme Development

The Biotechnology Division's research on enzyme development focuses on decreasing the cost of the enzyme used in the cellulose saccharification process. Researchers are applying recombinant DNA technology to bacteria and fungi to develop improved cellulase and other enzymes and to determine the most efficient method for producing these enzymes. Protein engineering efforts, including site directed and evolution strategies, have successfully improved cellulases and led to the discovery of new enzymes. Molecular modeling using MSI InsightII supports PCR based strategies to modify native genes and thus improve enzyme properties. Differential scanning microcalorimetery, circular dichroism, analytical ultracentrifugation, low angle light scattering detection (DAWN), laser particle size distribution analysis, and Zymark and Autogen robotics systems are tools used to conduct protein biotechnology research. Contact: Mike Himmel (303) 384-7756, michael_himmel@nrel.gov

**Strain Development**
Researchers are developing advanced microorganisms that can coferment all the sugars in biomass in order to improve biomass conversion economics. They are applying sophisticated metabolic engineering techniques to yeast, *Zymomonas mobilis*, *Lactobacillus*, and other bacterial species. The goal is to develop strains that can coferment both xylose and arabinose along with glucose. This work requires the ability to analyze and sequence DNA, isolate and purify genomic and plasmid DNA, and apply novel DNA introduction and transformation methods, in order to introduce new metabolic pathways. With industrial partners, researchers are working to develop designer strains for specific feedstocks, feed streams, and processes. Contact: Min Zhang, (303) 384-7753, min_zhang@nrel.gov

**Process Development and Integration**
A team of Biotechnology Division 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 model and improve specific unit operations within the process. Contact: Jim McMillan, (303) 384-6861, jim_mcmillan@nrel.gov.

**Process Engineering and Analysis**
A team of biochemical and chemical engineers focuses on bridging the gap between research and full-scale operations, which is critical for the scale-up and commercialization of biomass conversion technology. They perform complex process simulations that accurately predict the heat and material balances of biomass conversion processes and develop conceptual process designs and cost estimates for industrial scale facilities and thereby determine the feasibility of building and operating a biomass conversion plant. Contact: Kelly Ibsen, (303) 384-6855, kelly_ibsen@nrel.gov

**Life Cycle Analysis**
Conducting full life cycle analyses for all of the products of biomass conversion is important for determining environmental and economic feasibility. Biotechnology Division analysts use a life cycle inventory modeling package and supporting databases to conduct life cycle analyses on a global, regional, local, or project basis. Life cycle analyses have been carried out on Bioethanol from a number of different feedstocks and biodiesel from soybeans. New life cycle analyses on both bioethanol from corn stover and biodiesel from waste fats and grease are underway. Contact: John Sheehan, (303) 384-6136, john_sheehan@nrel.gov

## Facilities
Biotechnology Division scientists and engineers have access to state-of-the-art facilities including research laboratories for genetic engineering, protein engineering, microbiology, fermentation, enzyme production and purification, biomass pretreatment and hydrolysis, analytical chemistry, and a world-class process development unit. Many of these facilities can also be made available to industrial partners.

**Alternative Fuels User Facility (AFUF)**

Located on the NREL campus in Golden, Colorado, the AFUF is the cornerstone of DOE's biofuels research. It houses the Bioethanol Pilot Plant, an 8,000 $ft^2$ facility that includes five components (see the brochure at http://www.nrel.gov/docs/fy00osti/28397.pdf):

- **Process development unit (PDU)**
- The PDU is an integrated pilot plant for converting biomass to ethanol at a rate of 900 kg (1 ton) per day of dry biomass. Unit operations include feedstock washing and milling, thermochemical pretreatment, enzymatic hydrolysis and fermentation (four 9000-L fully instrumented fermenters), seed growth vessels (one 20-L, two 160-L, and two 1500-L fermenters), distillation (19 tray, 0.5 m in diameter, 10 m high sieve-tray column), and solid-liquid separations (continuous solid-bowl decanter and batch solid-bowl centrifuge).
- **Steam gun pretreatment laboratory**
- A batch 4-liter steam gun reactor uses high pressure and temperature for dilute acid pretreatment. It is easy to explore a wide range of reaction conditions with the steam gun system.
- **Continuous chromatography system**
- This Model L100C (Advanced Separation Technologies) continuous ion exchange system uses commercially available ion exchange resins to remove acetic acid and other fermentation inhibitors from liquid streams produced during biomass pretreatment or hydrolysis.
- **Countercurrent continuous hydrolysis pilot system**
- This patented reactor technology uses dilute acid and high temperature to achieve either pretreatment or cellulose hydrolysis while minimizing sugar degradation.
- **Fermentation mini-pilot unit**
- This unit offers aerobic or anaerobic batch, fed-batch, and continuous enzymatic hydrolysis and fermentation processing with a flexible system consisting of several vessels ranging from 10 to 100 liters. The system is capable of recycling biomass by ceramic filter or decanting continuous centrifuge (Bird, model HP200, Walpole, MA), and/or enzymes by ultrafiltration (Niro Hudson, Hudson, WI). Bioreactors are all by B. Braun and include Models B (5-L seed vessel), C (20-L), D (two, 100-L), E (two, 15-L), UD (20-L, 30-L, & 50-L).

**Protein Engineering**

A complete facility for enzyme modification and testing consists of three Perkin Elmer PCR machines, a Beckman Coulter LS 130 Particle Sizer, A Dionex PAD LC system for sugar analysis, a JASCO J-715 Spectropolarimeter, a Viscotek Differential Pressure Viscometer, a Schott-Gerate automatic capillary viscometer, a MicroCal Vapor Phase Scanning Microcalorimeter, a Beckman Optima XL-a Analytical Ultracentrifuge, a SPEX spectrofluorimeter, and a Cary Scanning Spectrophotometer. A 1200 $ft^2$ fermentation lab with six NBS BioFlo 3000 fermenters, two NBS MicroGen fermenters, and an NBS 150 L BL1-LS fermenter. A molecular biology lab with three dedicated laminar flow hoods. MSI Molecular Modeling software operated on an SGI ExtremeXT computer. A new 8-pack small scale fermentation system was recently installed.

**Protein Purification**

This facility is used to isolate enzymes from the μg to gram scale for subsequent biochemical and process characterization. It consists of 5 Pharmacia FPLCs, a Pharmacia Smart MicroLC, a Pharmacia BioPilot, a Pharmacia ATKA LC, numerous Amicon Ultrafiltration systems (pilot to bench scale), NBS continuous centrifuges, a Beckman PACE Capillary Electrophoresis system, a BioRad RF-2 Preparative Isoelectric Focusing system, and numerous bench equipment to conduct advanced enzyme assays. A 6 x 12' cold room permits large-scale ultraconcentration and handling of wild type and recombinant enzyme preparations at $4^{o}$C.

**Metabolic Pathway Engineering**

This 1,500 $ft^2$ facility includes two laminar flow hoods, 10 incubators, $-80^{o}$C freezers, a BioRad Gene Pulser, a UVP GDS7500 Gel Documentation System, numerous electrophoresis stations, a Southern hybridization station, numerous Perkin Elmer GenAmp PCR Systems, a Beckman DU640 Spectrophotometer, a Beckman CS-15R Centrifuge, a number of microcentrifuges, several Hewlett Packard 1090 series II HPLC systems, and a walk-in incubation room. This equipment has been used to conduct successful metabolic engineering experiments on bacteria and yeast which resulted in the development of new strains.

**Laboratory Robotics for High Throughput Screening**

CyberLab C-300 and C-400 decks with Zymark robotic area and peripherals including ovens, incubators, microtiter plate reader, bar code reader, and automated plate-sealing system are used to conduct automated protein assays based on 96- or 384 well microtiter format. These decks were initially designed to perform international filter paper assay. An AutoGen colony picker with ReArrayer, Gridder, and Replating modules is used to transfer bacteria and yeast colonies from petri dishes to microtiter plates.

# Capabilities for the Production of Chemicals from Renewables at the National Renewable Energy Laboratory

**Introduction**

NREL has pursued new technology to develop biomass as a viable and economical source of raw materials for the production of chemicals since its inception in 1976 and more recently as part of the National Bioenergy Center. Hence, NREL has developed a unique history in directly addressing these challenges. Despite the availability of an almost inexhaustible source of raw materials, the use of renewables lags far behind the use of nonrenewables, for the production of chemicals largely due to the lack of *technology development*. NREL has a continuing program of research directed at new technology and currently has over 50 staff members (scientists, engineers, and support staff) involved in chemical and biological separations and conversion of biomass resources into chemicals.

Key Contacts: Joseph J. Bozell, 303-384-6276 or Mark Finkelstein, 303-384-7755

**Research Area Capabilities**

The use of renewable feedstocks for chemical production can be divided into three broad areas: *conversion* (the transformation of raw materials into useful products), *separation* (obtaining the available raw materials from biomass) and *production* (i.e., farming). Of these three areas, NREL has strong research programs proceeding in conversion and separation. Our NBC partners at ORNL are strongest in production, but do chemical and biological conversions as well.

**1. Conversion** - Of these three components, *conversion* is the least developed for biomass. While the existing chemical industry has a wide number of high yield, selective conversion paths for their raw materials, the same cannot be said for the biobased products industry. Methodology to carry out conversions of biomass feedstocks comparable in efficiency and breadth to that used in the chemical industry is scarce. The technology for easy conversion of the building blocks of nature (sugars, lignin, oils) to useful chemicals is the primary stumbling block for wide use of renewables. Through a proper balance of fundamental and applied research, NREL has developed the knowledge necessary to carry out molecular level conversion of renewable building blocks with the same level of efficiency as the current nonrenewables industry.

**2. Separation** - Separation of biomass feedstocks is better developed than conversion. However, new, selective methods for the clean production of simple renewable building blocks analogous to those produced by the nonrenewables industry are important. NREL has developed, and continues to study new methods for the conversion of biomass into its constituent parts.

A partial list of successful projects carried out at NREL includes:

- Fundamental research on the use of catalysis and metal complexes for new processes for modifying the structure of simple sugars in a single step.
- The new media of ionic liquids are enabling technologies for the conversion of lignin and carbohydrates to new materials.
- Lignin based adhesives have been shown to perform well compared to existing commercial adhesives - at lower cost.
- Processes to produce low cost sugar streams suitable for both chemical and biological conversions have been developed
- New biocatalyst development for sugars conversion and cellulose hydrolysis
- An inexpensive sugar derivative, levulinic acid, has been demonstrated as a key starting material for the production of a new, powerful, but biodegradable herbicide, DALA
- A new process for the separation of cellulose gives a material superior to that currently used in industry for the production of cellulose esters and ethers.
- Lignin has been converted into a pulping catalyst
- An efficient synthesis of levoglucosan, a new chemical intermediate, from starch.

**Unique facilities**

Fully equipped organic synthesis labs, a thermochemical user's facility, support from a complete biomass analysis, biochemistry and microbiological facilities, polymer analysis labs, mechanical testing equipment, standard organic analytical facilities (NMR, IR, HPLC, GC, GC/MS).

Expertise and capabilities relevant to research areas

The conversion of renewable materials to chemicals covers an extremely broad range of disciplines. NREL possesses expertise and facilities in the following relevant areas:

***Strong capability or capability***: Organic synthesis, catalysis, biocatalysis, protein engineering, wood pulping, new biomass separation technology, ionic liquids, green chemistry, carbohydrate and lignin chemistry - Key contacts: Joseph Bozell, 303-384-6276, Luc Moens, 303-384-6265, Stephen Kelley, 303-384-6123, Bonnie Hames,, 303-384-6345; Mike Himmel, 303 384-7756; Min Zhang, 303 384-7753
***Capability*****:** Fuels from lignin - Key contact: David Johnson, 303-384-6263, Kelly Ibsen, 303 384-6855
***Strong capability***: Pyrolysis - Key contacts: Bob Evans, 303-384-6284; Stefan Czernik, 303-384-7703, David Dayton, 303-384-6216
***Strong capability or capability***: Polymers, Materials, Composites, Adhesives - Key contact: Stephen Kelley, 303-384-6123
***Interest***: Electrochemistry - Key contacts: David Johnson, 303-384-6263; Luc Moens, 303-384-6265

Collaborations essential to research area

NREL has ongoing or past collaborations with Eastman Chemical, Biofine, ADM, Allied-Signal, Cargill, CargillDow Polymers, Weyerhauser, Corn Refiners Assoc., National Corn Growers Assoc., New York State Energy Research and Development Authority, Louisiana Pacific, Champion International, Colorado School of Mines, Huntsman Chemical, Aker Industries, Georgia-Pacific Resins, Aristech, Ensyn International, Merichem, Genencor, Novo Enzymes, and several other DOE labs

.

## Capabilities in Biomass Analysis and Characterization

Introduction - NREL has been involved in analyzing biomass materials since 1978 as part of designing processes, monitoring processes, characterizing biomass resources, and developing new methods in biomass analysis and characterization. Annually, NREL has about 10-15 FTEs involved in this research area. A general contact is Gene Petersen, 303 275-2994 or Bonnie Hames, 303 384-6345 and web information can be found at http://www.nrel.gov/st-it.html; and http://www.nrel.gov/biotechnology/capabilities.html

| Area | Standard Biomass Analyses |
|---|---|
| Description | Typical wet chemical and spectroscopic analysis of biomass feedstocks and biomass-derived materials including solid wood, wood chips, grasses, wet biomass materials, etc.. Preparation and characterization of ASTM standards. Measure biomass derived fuels and fuels properties |
| Capabilities* & Contact Infor. | Strong capability: D. Johnson 303 384-6263; B. Hames 303 384-6345; Ray Ruiz (303) 384-6141; David Templeton (303) 384-6831 |
| Collaborators | BC International, Virginia Polytechnic Institute, ORNL, Pulp and paper companies |

| Area | Process Monitoring and Control – *Thermochemical* |
|---|---|
| Description | Monitoring of high and low temperature biomass pretreatment and conversion processes with range of spectroscopic and chromatographic methods. Processes include wood, grasses, and a wide range of plastics (nylons, urethanes, cotton/polyester, thermosets, etc.). |
| Capabilities & Contact Infor | Strong Capability: R. Evans 303 384-6284; D. Dayton 303 384-6216; M. Ratcliff 303 384-6129 |
| Collaborators | U. of Utah, Sandia National Laboratories, Institute for Paper Science and Technology, FERCO, Battelle Memorial Institute, Georgia Tech, Air Products |

| Area | Process Monitoring and Control – *Biological/Aqueous* |
|---|---|
| Description | Monitoring biomass pretreatment and conversion processes with range of spectroscopic and chromatographic methods. Specialized analysis of biomass digestibility |
| Capabilities & Contact Infor | Strong capability: J. Farmer 303 384-6154; J. Baker 303 384- 7770 |
| Collaborators | BC International, Auburn U. |

| Area | Advanced Analytical and Process Control Technologies |
|---|---|
| Description | Spectroscopic analysis of biomass composition and properties in real time. Biomass feedstocks and biomass-derived materials including solid wood, wood chips, grasses, wet biomass, microbial mass, etc. Analytical tools for forest products industry. Can measure mechanical properties of wood and wood composites. Chemometrics applied to analysis of biomass. |
| Capabilities & Contact Infor. | Strong Capability: S. Kelley 303 384-6123; M. Davis 303 384-6140; B. Hames 303 384-6345 |
| Collaborators | Analytical Spectral Devices, Weyerhaeuser, Louisiana Pacific, Georgia Pacific Resins, Ensyn Intern., Boise Cascade, Champion (now International) Paper, Tembec, USDA's Southern Research Station, Aker Industries, Huntsman Chemicals, Rayonier, Midwest Research Institute, Purdue U., Oregon State U., Auburn U., Alabama U, U. Maine, U. UmeΔ. |

Unique or specialized facilities

| Area | Molecular Beam Mass Spectrometer |
|---|---|
| Description | One stationary and two transportable units. Stationary unit can handle 1300 C process streams. The transportable units can handle 350C process streams. Units are quadrapole type direct sampling, free-jet mass spectrophotometers adapted for interface with processes. General analysis of biomass with applications in genetic screening of plants, analysis of soils, kinetics of biomass combustion & others |
| Capabilities & Contact Infor. | Strong Capability: Bob Evans 303 384-6284<br>Matt Ratcliff 303 384-6129 |
| Collaborators | USDA's Western Regional Research Center, & Northeastern Regional Research Station, Michigan Technological Institute; Oak Ridge National Laboratory; Philip Morris, Air Products |

| Area | Combustion Kinetics Mass Spectrometer |
|---|---|
| Description | Time of flight mass spectrometer for monitoring biomass combustion process. Hyperthermal nozzle and laminar entrained flow reactor development |
| Capabilities & Contact Infor. | Capability: David Dayton 303 384-6216 |
| Collaborators | U. Colorado, University of UmeΔ, Sweden; VTT Finland, Air Products, IPST |

| Area | Nuclear Magnetic Resonance Instruments |
|---|---|
| Description | 300 and 400 MHz small bore liquid instruments ; 200 MHz wide bore solids instrument. Special applications to analysis of biomass and biomass components such as lignin and cellulosics and their interactions. Analysis to increase understanding of genomics in biomass. |
| Capabilities & Contact Infor. | Capability: Buzz Curtis 303 384- 6270 Mark Davis 303 384-6140 |
| Collaborators | Argonne National Laboratory, U. Colorado |

Other unique capabilities or facilities related to bioenergy and biobased products

| Area | Cryospectroscopy |
|---|---|
| Description | Matrix isolation of chemical species at cryogenic temperatures allows for spectroscopic analyses of transient species |
| Capabilities & Contact Infor. | Interest: J. Radziszewski 303 275-3833 |
| Collaborators | Colorado School of Mines, Vanderbilt U, U. Colorado, Roskilde University, Denmark, Polish Academy of Sciences |

| Area | Photocatalytic Oxidation |
|---|---|
| Capabilities & Contact Infor. | Capability: D. Blake 303 275-7701; K. Magrini 303 275-7706 or E. Wolfrum 303 275-7705 http://www.nrel.gov/research/industrial_tech/pollution.html |
| Collaborators | Lennox Corp, PPG, Marsulex, US Air Force |

* Strong capability means >24 FTEs involved in this area over the past 5 years; Capability means >9 but <25 FTEs involved in this area over the past 5 years; Involvement means < 9 FTEs involved in this area over the past 5 years; and Past Capability >2 FTEs/year involved in this area over 5 years ago.

## CAPABILITIES IN THERMOCHEMICAL CONVERSION RESEARCH

Introduction

NREL has performed R&D in the conversion of renewables resources into fuels and chemicals for over 25 years. These capabilities have been developed under both programmatic funding and PI lead projects from the EERE Offices of Power, Transportation and Industrial Technologies. Detailed research area descriptions, pictures, and publications resulting from much of this can be found on the following websites: http://www.nrel.gov/documents/biomass_energy.html; http://www.nrel.gov/research/industrial_tech/ip_prog.html; http://www.nrel.gov/research/industrial_tech/tcuf.html.
**Key Contact:** Richard Bain, 303 275-2946

Thermochemical Processing Systems

R&D at NREL includes both applied and fundamental research into the mechanisms of combustion and combustion kinetics of pyrolysis, combustion, and gasification processes for a wide variety of biomass feedstocks. In addition, the thermochemistry for processing a large range of plastics has also been evaluated at NREL. The following is a representative list of the kinds of feedstocks or processes evaluated for their mechanisms and kinetics under Thermochemical processing:

- Wide range of hard and soft woods, bagasse, peanut shells, cellulose fibers, corn fiber, residues from municipal solid waste (nonmetallic), straws, and others
- Black liquor
- Nylon 6 and Nylon 6,6 carpet, polyurethane, cotton/polyester, polycarbonates, phenolic resins, etc.
- Oxidation of biomass in supercritical carbon dioxide
- Hydrotreating of lignin
- Delignification of wood
- Fractionation of biomass into clean fractions of cellulose, lignin, and hemicellulose
- Fractionation of corn fiber into component streams
- Steam reforming of pyrolysis oils for hydrogen production

**Specific Contacts:** Steve Phillips 303 384-6235; Ralph Overend, 303 275-4450; Bob Evans 303 384-6284; David Dayton 303 384-6216; David Johnson 303 275-6263; Stefan Czernik 303 384-7703; Esteban Chornet 303 384-7707; Matt Ratcliff 303 3846129

**ThermoChemical Users Facility (TCUF)**

The TCUF can be configured to accommodate the testing and development of various reactors, filters, catalysts, or other unit operations. Scales range from 0.1 kg/hr for bench-scale reactors to 20 kg/hr in the Thermochemical Process Development Unit (TCPDU). Users can obtain extensive performance data on their process or equipment, quickly and safely.

Customers can avail themselves of NREL's experienced staff of scientists and engineers to plan and conduct experiments and interpret data using the latest statistical techniques. The facility can provide users, sponsors, and customers with timely and useful data for evaluation of processes, materials, feedstocks, and products.

Description of facilities:

**Reactor Type** (*The TCPDU is designed for easy installation of any reactor type)*

- Cyclonic • Bubbling fluidized bed • Circulating fluidized bed

**Char Removal** (*Other filtering equipment can be installed as needed, even during the same run)*

- *High-efficiency cyclones • Baghouses • Ceramic filters*

**Secondary Reactors**

- Quick-contact thermal cracker
- Circulating riser cracker coupled with steam stripper and catalyst regenerator.

**Condensation**

- Direct-contact condensation train.

**Tar Removal from "Dirty" Syngas**

- Condensation train operated in wet scrubbing mode
- Catalytic tar cracking.

**Gas Polishing**

- Electrostatic precipitators
- Coalescing filters.

**Syngas Upgrading to High-Value Products** (*Authentic syngas can be bottled and shipped to a customer's facility for testing in their equipment.*

- Catalytic synthesis unit

## Product Analysis

NREL's TCPDU facility and laboratories are unique in that they can analyze products on-line over a wide spectrum of chemical compositions using dedicated analytical instruments operated by trained technicians and scientists. The TCPDU's state-of-the-art process control system is interconnected with the analytical instruments' control computers to create a single integrated database. Chemometric computer analysis of all collected data can be used for rapid process optimization.

The on-line and stand-alone analytical instruments available for characterizing the conversion products include:

- Molecular Beam Mass Spectrometer; Transportable Molecular Beam Mass Spectrometer; Fast Fourier Transform Infrared Spectrometer; Non-Dispersive Infrared Spectrometer; Microsensor Technology Rapid-Cycling Gas Chromatograph.
- The TCUF's analytical capability can be taken on the road to provide on-line sampling at a customer's site.

## Other Capabilities

- Bench-scale fluid-cracking-catalyst-like unit operation for testing 500-gram quantities of catalyst; Catalytic Steam-Reforming Unit; 2", 4", and 8" fluidized-bed reactors (1 atm) with filtering, condensation trains, and electrostatic precipitators; High-pressure batch and continuous-flow reactors; Micro Activity Test Unit; Solvent Vapor Cracking Unit; Catalyst synthesis; Training in gasifier fundamentals and operations.
- Three unique, direct, free-jet, MBMS sampling systems are used at NREL. One is a laboratory instrument with a triple quadrupole detection system for tandem-mass spectrometric identification of isomeric ions. The other two are transportable systems (TMBMS) with quadrupole detectors. These systems are designed to permit field sampling of effluents, exhausts, stack and process vapors and gases, etc. as well as use in the laboratory. The MBMS provides a complete spectrum in times as short as 200 milliseconds. Absolute quantification of chemical species is possible using the MBMS, however, it is not routine. We presently perform quantitation of species including hydrogen, benzene, naphthalene, and alkali metals fairly routinely in the parts per million by volume (ppmv) concentration range

Examples of fundamental studies conducted with these facilities

Laboratory study of high-temperature, atmospheric-pressure chemistry involving unstable, reactive and condensable species has been a significant part of NREL's effort. The extensive use of multivariate analysis of complex mass spectra is an integral tool in interpretation of MBMS data.

- Alkali and heavy metal release from biomass combustion and gasification
- Fundamental thermodynamics and kinetics of alkali and heavy metal vapor species
- Thermodynamic modeling of combustion/gasification systems
- Laminar entrained flow reactor development for combustion, cofiring, gasification, and pyrolysis studies.
- Tar formation pathway and kinetics in black liquor and biomass gasification
- Catalytic reaction studies, such as cracking and steam reforming of gasifier tars
- Development of Empirical Model of Biomass Pyrolysis
- Selective Oxidation
- Development of Relational Multivariate Data Base to be used as Library during real time analysis campaigns
- Analytical pyrolysis of biomass feedstocks and products for rapid compositional analysis.
- Thermal pretreatment for the recovery of coproducts prior to thermal conversion
- Combinatorial Catalyst Screening using MBMS
- Identification and characterization of reaction products and intermediates
- Kinetics of biomass thermochemical processes

Collaborations

Hercules, Battelle, Institute of Gas Technology, Institute of Paper Science and Technology, Ensyn, Louisiana Pacific, Georgia Pacific Resins, Neste, Aristech, Merichem, Future Energy Corporation, Community Power Corporation, U. Puerto Rico, Pyrolysis Materials Research Consortium. Have garnered an R&D 100 Award for producing phenolics from biomass for substitution of phenol in resins and adhesives.

Campaigns that have been undertaken at various facilities

| Date | Location | Process |
|---|---|---|
| 1992 | NREL Solar Furnace Facility | Solar assisted hazardous waste combustion |
| 1993 | CIFER, Denver, CO | Diesel emissions monitoring |
| 1993-1994 | Battelle, W. Jefferson, OH | Indirect biomass gasification and catalytic tar destruction |
| 1994-1995 | IGT, Chicago, IL | High pressure air gasification of bagasse and hot gas clean-up |
| 1996 | NREL Solar Furnace Facility | Solar conversion of bromine to hydrogen bromide |
| 1997-1998 | NREL Thermochemical User Facility | Gasification and pyrolysis R&D |
| 1999-2000 | Battelle, W. Jefferson, OH | Indirect biomass gasification and catalytic tar destruction |
| 3/00-7/00 | Institute of Paper Science and Technology, Atlanta, GA | Pressurized, entrained flow black liquor gasifier – tar measurements |

# Oak Ridge National Laboratory (ORNL) Capabilities
# in
# Bioenergy Crop Development

The development of new plant materials and production systems for bioenergy is a key focus of work supported by the DOE Offices of Transportation Technologies and Power Technologies. ORNL staff provide management leadership for the Bioenergy Feedstock Development programs. Some related ORNL research to improve sustainable forestry productivity and management techniques is funded through the DOE Office of Industrial Technologies. Total funding for ORNL and collaborators for both area of work has ranged from $2.5 to $3.5 million annually over the past 10 years. Detailed research area descriptions, pictures, and publications (full text or references) can be found on the website: http://bioenergy.ornl.gov . Information on related capabilities can be found at http://.esd.ornl.gov.
**Primary Contact: Lynn Wright, (865) 574-7378, wrightll@ornl.gov**

**Research Area Descriptions**

**The Woody Crops** research mission is to maximize per-unit area productivity in order to optimize economic returns, reduce environmental impacts, and establish sustainable biomass supply systems for the production of bioenergy and bioproducts. This involves a focus on members of the *Populus* and *Salix* genera for application to a substantially large portion of the United States through the use of advanced silviculture, insect and disease protection, traditional breeding, and molecular genetics. The research is organized around regional crop development consortia consisting of universities, U.S. Department of Agriculture research units, and industrial cooperators.
Contact: Gerald Tuskan, (865) 576-8141, tuskanga@ornl.gov

**The Herbaceous Crops** research mission is to evaluate and develop herbaceous crops that can be produced on American farms to provide a sustainable, cost-competitive source of renewable feedstocks for liquid fuels and power. The focus is on Switchgrass (*Panicum virgatum*), a native perennial warm season grass that is both highly productive and well suited to diverse agricultural sites. The regionally organized research includes breeding and agronomic activities in 2-3 major crop growing regions.
Contact: Sandy McLaughlin, (865) 574-7358, mclaughlinsb@ornl.gov

**The Environmental Sustainability** research mission is to provide the quantitative environmental data required to determine how bioenergy crops can be established, managed, harvested, and used for energy in a manner that also provides benefits for soil and water quality, and biodiversity. The research is coordinated with woody and herbaceous crop development, and with integrated analysis to ensure efficiencies in the use of research sites, the use of consistent protocols for collecting and reporting data, and to provide comprehensive results for biomass cropping systems.
Contact: Virginia Tolbert, (865) 574-7288, tolbertvr@ornl.gov

**Unique Facilities for Crop Development Research**
The Oak Ridge National Environmental Research Park (NERP) is located on land owned and controlled by DOE. The ~10,000 ha research park allows scientists the opportunity to investigate environmental issues in the context of complex geological and hydrological systems as well as in the context of historical land-use change. Significant numbers of acres currently in pasture land and loblolly pine may have potential for management as a bioenergy resource or as a location for bioenergy crop research.

Plant and microbial genomic research utilizes the Genomics Laboratory which includes a DNA analyzer coupled to an automated workstation, a fluorescence-activated cell sorter equipped with 350nm UV and 488 lasers, a DNA chip machine, and a cryogenic storage freezer.

Forest growth, tree physiology and nutrient cycling are being evaluated at the Global Change Research Facilities. Included on the site are (1) open-topped chambers being used to examine the effects of elevated levels of atmospheric $CO_2$, temperature, and tropospheric ozone on vegetation; and (2) a Free Air $CO_2$ (FACE) facility in a closed canopy, 12-m tall, sweetgum (*Liquidamber styraciflua*) forest plantation. Elevated $CO_2$ exposure at a concentration of 200 ppm above ambient in the FACE facility began in the spring of 1998.

**Expertise relevant to Bioenergy Crop Development**

ORNL has 21 years of experience in management of the Bioenergy Feedstock Development Programs with national application. Program management support activities include database management, data synthesis, website management and communication of feedstock program research results to the national and international community. Nine individuals representing about 6 person years have a combined experience in these areas of about 90 years.

ORNL currently has 13 permanent scientific staff with expertise in the area of plant physiology and biotechnology within the Environmental Sciences Division . Current research activities related to bioenergy include:

- research on willow gender determination,
- physiological research on short-rotation woody crop growth in the southeastern U.S.,
- switchgrass basic physiology research, and gene sequencing.
- Investigation of the genetic control of carbon allocation in woody plants (joint with NREL)

ORNL additionally has 14 permanent scientific staff associated with the Ecosystem Sciences part of the Environmental Sciences Division. They focus on global carbon cycling, natural ecosystem responses to stress, nutrient cycling, etc. Current activities related to improving the environmental benefits of biomass cropping systems include the following.

- management of the environmental sustainability research area,
- research on the effects of switchgrass, and woody crops on soil carbon levels
- comparisons of carbon under grass, woody and agricultural crop systems,
- sustainable forestry management systems, and sustainable forestry modeling.

**Collaborations Essential to ORNL's Crop Development Capability**

The crop development research lead by ORNL is an existing model for a "virtual" labortory. The facilities and capabilities of ORNL are blended with those of other institutions through the nation through subcontracts, interagency agreements, and handshakes to create a interconnected body of scientists working on energy crop and cropping systems. National and regional coordination is facilitated by ORNL reasearch area leaders. Collaborators bring a range of 10% to 100% cost-sharing to the collaborative efforts. Most primary collaborators with ORNL have additional collaborators, often industrial, who provide extensive "in-kind" cost-share.

Primary collaborators for the three research areas above include the following.

Alabama A&M University
Auburn University
Iowa State University
International Paper Co.
Michigan State University
Mississippi State University
Ohio State University/American Electric Power
Oklahoma State University
Oregon State University (Tree Genetic Engineering Cooperative)]
State University of New York
Texas A&M University
Tennessee Valley Authority
University of Georgia
University of Idaho
University of Tennessee
Virginia Tech University
Washington State University
University of Washington (Popular Molecular Genetics Cooperative)
University of Minnesota/ Agricultural Utilization Research Institute ( Minnesota Hybrid Poplar Research Cooperative)

USDA Agricultural Research Station in Lincoln Nebraska/ North Dakota State University
USDA Agricultural Research Stations in Midwest (5 sites doing soils research)
USDA Plant Materials Centers (several)
UDSA, Resource Conservation Development Districts (Chariton Valley in Iowa and WesMin in Minnesota)
USDA Forest Service, North Central Forest Experiment Station/University of Minnesota,
USDA Forest Service, North Central Forest Experiment Station/ Rhinelander
USDA, Forest Service Southern Experiment Station/North Carolina State University,
USDA, Forest Service, Southern Experiment
Station/Savannah River Site ( Short Rotation Woody Crops Cooperative of the Southeast

## Oak Ridge National Laboratory Capabilities
## in
## Bioenergy Systems Integration, Analysis and Engineering

ORNL staff (and subcontractors) conduct economic and engineering analysis, and gather data in support of bioenergy technology development, project development, policy development and market penetration. This work is primarily funded by the DOE Offices of Transportation Technologies and of Power Technologies at a level of $2 – 3 million annually. Several other offices of DOE provide funds for analysis capabilities which are complementary to and supportive of those needed for bioenergy systems integration. Results of most analysis can be found on the website: http://bioenergy.ornl.gov/.

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### Research Area Descriptions and Key Collaborators

**Integrated Analysis** provides biomass resource, environmental, and economic evaluations needed by policy makers, the private sector, and others interested in the development of biomass energy systems. Activities include the development and maintenance of (1) internet available resource databases, (2) economic models of crop production and supply logistics, (3) linking of economic and environmental models, and (4) development and use of analysis models including an agricultural sector demand model, a GIS-based transportation model, and others. A key collaborator in the conduct of this task is the agricultural economics group at the University of Tennessee.
Contact: Marie Walsh, (865) 576-5607, walshme@ornl.gov

**Operational Support and Evaluation** activities document and quantify bioenergy feedstock production practices, productivities, environmental effects, and costs under operational conditions. Data collected becomes input to the Integrated Analysis and Systems Engineering activities and are a source of information to assist DOE in evaluating project opportunities. This activity communicates information on energy crop technologies to the bioenergy project development community, equipment developers, and others requiring specific information based on operational experience. Bioenergy project developers and the Regional Biomass Energy Programs are key collaborators in this effort.
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**Systems Engineering** research develops information and models on collection, storage, and transportation of biomass feedstocks with the goals of reducing costs and establishing safe and environmentally and economically sustainable supply systems. The task initiates fundamental engineering research, supports environmental and equipment field trials, and performs research on physical and chemical characterization of biomass to assist in designing optimal handling strategies. Current research is focused on crop residues (straw and stover) for biofuels end uses but research relevant to all types of biomass feedstocks is anticipated. NREL and the University of Tennessee are currently the key collaborator, collaborations with USDA and the equipment industry are being developed.
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**Residue Information** is being collected and generated with the goal of expanding the bioenergy use of urban and industrial wastes, logging residues, and other forest resources not currently being used. Information collected on residues includes sources, estimates of quantity, characteristics, current disposition, environmental risks and benefits of use, handling, storage, and transport issues, and effects of conversion requirements on residue usefulness. This information is fed into models developed for integrated analysis to estimate cost and supply relationships for different regions of the country. USDA Forest Service databases are a significant source of information, key collaborators are consultants such as Antares Group. Contact: Robert Perlack, (865) 574-5186, perlackrd@ornl.gov

**Ethanol Market Penetration** assessment has involved use of the ORNL Refinery Yield Model and ORNL resource supply cost information in collaboration with other groups to estimate demand curves for ethanol blended gasoline. A significant finding is that the demand for ethanol is reduced as the volumes of reformulated gasoline increase. Key collaborators to this efforts included NREL and the consultant group, TMS.
Contact: Gerald Hadder, (623)-322-2406, haddergr@ornl.gov

**Biomass Power Market Penetration** is a new area of assessment being addressed by ORNL staff in collaboration with NREL. Models being evaluated for this activity includes the National Energy Modeling System (NEMS) preferred by DOE's Energy Information Administration, an Integrated Planning Model (IPM$^{TM}$) developed by ICF Consulting, and the Oak Ridge Competitive Electric Dispatch Model (ORCED) developed by Stan Hadley.
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**Unique Resources Supporting Bioenergy Systems Integration, Analysis and Engineering**
The analysis capability at ORNL depends on the development of analysis tools. Analysis tools developed or used at ORNL are often linked with or provide input into analysis tools developed by others to arrive at complete analysis capabilities. Just a few of the analysis tools developed by ORNL include the following:

- BIOCOST – a crop production full-cost calculation model
- ORRECL – a county level biomass resource database (with potential crop yield and land use information)
- ORIBIS – a GIS-model to evaluate transport costs and optimal facility siting based on feedstock costs)
- POLYSYS – a USDA supported agricultural sector demand model including energy crops (developed by University of Tennessee in collaboration with ORNL)
- Refinery Yield Model – models transportation fuel supply and demand interactions given various policy options or regulations
- ORCED –is a regionally based competitive electric dispatch model which contains information on all power plants in the U.S
- Biomass supply logistics models currently under development
- A biomass resource database with state level information on estimated prices and quantities of forest, mill and agricultural residues, urban wood residues and energy crops
- 20 years of interim and final research reports on crop and environmental research
- Databases (mostly archived) of actual research results from the 1980's and early 1990's

- Files of literature (mostly in a bibliographic database) on biomass resources research
- The Geographic Information Systems laboratory is a computational workstation network that utilizes SUN ULTRA and ARC/INFOtm and is equipped with digitizing, GPS, digital photography and scanning technologies, and a rich library of local and national geographic data which can be used for landscape and regional environmental research and analysis

**Complimentary Capabilities and Resources**

The Ecosystem and Global Change Science area within the Environmental Sciences Division at ORNL is conducting research that provide information resources and analysis tools of potential value to bioenergy analysis. The overview can be found at: http://www.esd.ornl.gov/research/index.html. Important Centers associated with that science area include: The Carbon Dioxide Information and Analysis Center (CDIAC) http://cdiac.esd.ornl.gov and the newly formed Center for Research on Enhancing Carbon Sequestration in Terrestrial Ecosystems (CSiTE) http://csite.esd.ornl.gov. The latter is actually led by a consortium of DOE's Oak Ridge, Pacific Northwest, and Argonne National Laboratories. CSiTE field research will take place at several sites, including the DOE's National Environmental Research Parks at ORNL and the Fermi National Accelerator Laboratory, U.S. Department of Agriculture sites in Alabama and South Carolina, the Rodale Institute Research Center in Pennsylvania, and forest industry research sites in the Pacific Northwest and the Southeast.

The Center for Energy and Environmental Analysis of the Energy Division at ORNL also has several ongoing activities that are complimentary to and representative of types of analysis that may be needed for Bioenergy Systems Integration and Analysis. Examples include studies on land use planning, socioeconomic effects of technology change, natural resource management, and others. More information on those activities can be found at http://www.ornl.gov/ceea/index.html

The high performance parallel computers and storage systems of the ORNL Center for Computational Science are available for computationally-intensive analysis applications.

## Pacific Northwest National Laboratory
## Bio-Products Research

The Pacific Northwest National Laboratory has been involved in bio-products research since the mid-1970s, developing and applying novel thermal, chemical and biological processes to convert biomass to industrial and consumer products, fuels, and energy. The hallmark of PNNL's research has been novel catalytic processes that convert sugars and organic acids to much higher value commodity and specialty chemicals. These products typically have a higher market value than biomass-derived fuel or energy, and the current worldwide market place is very promising. For more information, contact Dennis Stiles, Program Manager, Bio-Based Products, (509) 372-4358 or dennis.stiles@pnl.gov.

### Research Area Descriptions

**Novel Catalyst Research**

PNNL is developing new catalyst formulations and demonstrating their utility in process applications for production of bio-based chemicals. Novel high-activity catalysts for hydrogenation and oxidation in condensed phase conditions use noble metals and stabilized base metals for catalysis. Also under development at PNNL are stable catalyst support materials including metal oxides and carbons for aqueous phase processing.

Applications of PNNL catalysis processes include:

- Catalytic hydrogenation of organic acids to monomers, esters, and solvents
- Catalytic hydrogenation of sugars to produce monomers and esters
- Catalytic hydrogenation of levulinic acid to monomers and a fuel oxygenate
- Catalytic oxidation of oils to produce monomers, esters, and epoxides

**Eukaryotic Organisms in Fermentation and Enzyme Discovery**

PNNL has a group dedicated to fully exploiting the capabilities of filamentous fungi, the group of microorganisms largely responsible for recycling lignocellulose biomass in nature and the source of beta lactam antibiotics, the miracle drugs of the mid-twentieth century. These eukaryotic organisms have been relatively ignored for development of new fermentation systems and enzyme discovery and only a few of the hundreds of thousands of known fungal species are used to make useful products via large-scale culture. As these organisms are less well studied and generally less exploited than other groups of microbes, PNNL has established the capacity to study and manipulate them by building a culture collection for discovery, characterization, and product screening, establishing a fermentation laboratory, and developing novel molecular biology tools for genetic manipulation of the fungi as part of developing optimal production systems.

Applications of this new capability include:

- Development of novel fermentation systems to produce new chemical feedstocks
- Discovery of new enzymes useful in processing biomass and derived products
- Improvement of existing enzyme or acid production strains

**Separations and Other Supporting Process Technology**
PNNL designs, develops, and deploys integrated processing suites to produce high-value chemicals and fuel components from agricultural biomass and other low-valued feedstocks. These systems often require new processing concepts and systems development and PNNL addresses all of the steps in the complete processing scheme, from feedstock pretreatment to purified product recovery. Included in PNNL process research are basic science and engineering capabilities, applied to biomass pretreatment to ensure effective recovery of optimal value from biomass, carbohydrate polymer systems to maximize energy efficiencies, and advanced micro-technology systems for separation and conversion processes.

Applications include:

- Selective recovery/removal of chemical products and contaminants from aqueous and gaseous streams to increase process yield and purify products
- Development of miniaturized unit operations and processes on microtechnology architecture for cost-effective production of chemicals and treatment of wastes
- Efficient separation of low-value fiber into starch, sugar, lipid and protein fractions while minimizing unwanted by-products
- Characterization of costs and impacts of renewable feedstocks and novel conversions throughout the value chain and product life-cycle

**Unique Facilities**
PNNL's advanced bio-based products research is due in large part to the distinctive equipment at the Laboratory. Representative examples include the state-of-the-art nuclear magnetic resonance (NMR) and electron paramagnetic resonance (EPR) instrumentation located in the William R. Wiley Environmental Molecular Science Laboratory, on the research campus in Richland, Washington. PNNL's Chemical Engineering and Process Development Laboratories also offer highly advanced chemical analytical equipment and chemical and biochemical reactor systems, such as batch and continuous flow catalytic reactors in which to perform a diverse range of hydrogenation and oxidation reaction steps. Other facilities provide capability to operate batch fermentation vessels, to collect and screen microbes, to conduct genetic sequencing, and to carry out metabolic engineering experiments using microbes and plants.

**Collaborations**
PNNL's research has been conducted in collaboration with several grower associations, commodity processors, chemical companies, and university partners. Collaborative partnerships, many formed via Cooperative Research and Development Agreements (CRADAs), include current projects with the National Corn Growers Association, the Iowa Corn Promotion Board, Archer Daniels Midland Corporation, Pendleton Flour Mills, Mennel Milling, DeGussa, and Engelhard. University collaborations include Washington State University, Michigan State University, and the University of Montana. Noteworthy collaborations in the past include process development research projects with Applied CarboChemicals and the Biofine Corporation, which resulted in an R&D 100 Award and a Presidential Green Chemistry Challenge award, respectively.

# Sandia National Laboratories Capabilities
# in
# Biomass Combustion Technology and Industrial Sensors

Staff at Sandia's Combustion Research Facility (CRF), a designated DOE user facility, are leading experts in the fields of combustion research and advanced diagnostics, including applications to combustion of biomass-derived fuels. Our work on biomass combustion is primarily funded by DOE's Office of Power Technologies (OPT) Biomass Power Program. This work leverages research facilities, as well as unique expertise in laser diagnostics and combustion-process modeling, developed through long-standing support of the CRF by DOE's Office of Science/Basic Energy Sciences (BES), Office of Industrial Technology, and Office of Fossil Energy/National Energy Technology Laboratory (FE/NETL). Our work on cofiring of coal and biomass has been supported jointly by OPT and FE/NETL. General information about the CRF and many of our research capabilities can be found on the website: http://www.ca.sandia.gov/CRF.

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**Research Area Descriptions and Key Collaborators**

**Multifuel Combustor (MFC)**
The MFC is used to investigate the overall combustion processes and emissions produced from combustion of a wide range of gas, liquid, and solid fuels, including biomass flash pyrolysis oils, agricultural residues, and various woody and herbaceous fuels. Extensive research has been performed on steam-tube deposit formation from biomass fuels, both as the sole fuel source and as cofired with various coals. New information on the mechanisms of formation and properties of ash deposits formed during biomass combustion has been developed through extensive testing in the MFC. The information was compiled and interpreted in the final report on the Alkali Deposits Project. Devolatilization rates and total volatiles yields of several biomass fuels were determined recently under boiler-relevant conditions. The focus of our current research is on the formation and control of $NO_x$ and fine particulates during combustion of biomass fuels when fired alone and during cofiring of biomass with coal. Collaborators include Bryan Jenkins of the University of California at Davis, David Dayton of National Renewable Energy Laboratory (NREL), Mark Downing of Oak Ridge National Laboratory (ORNL), and Franz Winter of the Technical University of Vienna.
Contacts: Linda Blevins, (925) 294-4811, lgblevi@sandia.gov
Ben Wu, (925) 294-2015, bcwu@sandia.gov

**Field Test Technical Support**
Sandia has extensive experience in providing expertise on combustion processes and instrumentation in support of field tests in biomass- and coal-fired power generation systems, as well as for testing in furnaces used by US manufacturers in the glass, chemicals, refining, and forest products industries. In the Biopower area, we developed and installed the data acquisition system used to record operational data at the recent Chariton Valley switchgrass cofiring demonstration. We are also working closely with the Hawaii Natural Energy Institute (HNEI) and Hawaiian Commercial & Sugar Co. (HC&S) to develop and implement a series of tests cofiring cane-derived fuels with coal in existing boilers as a demonstration of closed-loop

biomass power production. We have measured gas and particulate properties during tests at the Wheelabrator Shasta Energy power plant in Anderson, California, operating on hog fuel. In related work, Sandia is currently developing two laser-based instruments that measure, *in situ*, physical and chemical properties of entrained fume and carryover particles in recovery boilers used by the pulp and paper industry.

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**Advanced Combustion Laboratory (ACL)**

The ACL is a new facility being developed at the CRF, to permit advanced research and development of sensors for process-control for application to biomass- and coal-fired power generation processes, operating at atmospheric pressure and at elevated pressures (up to 20 bar), in a variety of gaseous environments. This facility is being developed by leveraging resources from OPT/Biopower, NETL/Advanced Research, and OS/BES. This facility will become operational during FY02.

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**Char Combustion Laboratory (CCL)**

In this laboratory, an optical particle-sizing pyrometer is used in association with a high-temperature, combustion-driven entrained flow reactor to quantitatively measure char combustion kinetic rates and elemental release rates for various solid fuels, including coal, coke, and biomass flash pyrolysis chars. In addition, this laboratory houses a captive particle imaging device that allows simultaneous visible and infrared imaging of burning particles. The imaging gives information on the evolution of char burning rates as a function of burnout as well as information on char fragmentation and mode-of-burning during combustion. These data have, over the past twenty years, provided essential inputs to engineering process models used in furnace-design codes by US combustion-equipment manufacturers.

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**Biomass Fuels Combustion System (BFCS)**

The BFCS was developed in the early 1990's to conduct research into the predominant processes occurring during combustion of biomass flash pyrolysis oil droplets. Both mass-produced oils provided by Ensyn and small batch oils produced by NREL were investigated. The influence of water content and of char content on the burning rate and microexplosion behaviors of the oils were determined and explained. A final project report was written in collaboration with Fortum's Steven Gust and published in 1999.

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**Research Program**

The ERRC is one of four Federal regional research centers in ARS, USDA, established by Act of Congress in 1938, for fundamental, applied and developmental research on agriculture commodities. Its mission, funded with $27.6 mil, is new knowledge and technology for an abundance of high quality agricultural commodities and products at reasonable prices ensuring continued improvement in the standard of living of all Americans. Research capabilities with impact include: develop new and improved food and nonfood or industrial products and energy efficient processing technologies; upgrade nutritional value of foods; ensure microbial and chemical food safety via molecular biology studies, rapid detection-sensing methods, intervention technologies and risk assessment; decrease costs for production of fuel-grade alcohol and biodiesel from agricultural feedstocks; utilize by-products, particularly potential pollutants; open new and expand existing domestic and foreign markets; reduce marketing costs and transfer technology to stakeholders.

The ERRC has seven Research Units - Dairy Products; Engineering Science, Food Safety; Hides, Lipids and Wool; Microbial Biophysics and Biochemistry and Core Technology; Microbial Food Safety; and Plant Science and Technology. Two Work Sites, University of Maryland Eastern Shore and Delaware State University with microbial food safety programs report to ERRC.

**Biobased Products, Biofuels Research Programs**

Research and development thrusts at ERRC are in two ARS National Programs.

1. New Uses, Quality and Marketability of Plant and Animal Products -
To enhance the economic viability and competitiveness of U.S. agriculture by maintaining the quality of harvested agricultural commodities or otherwise enhancing their marketability, meeting consumer needs, developing environmentally friendly and efficient processing concepts, and expanding domestic and global market opportunities through the development of value-added food and nonfood products and processes.

2. Bioenergy and Energy Alternatives -
To create jobs and economic activity in America, reduce the Nation's dependence on foreign oil, and improve the environment by developing alternate energy sources and increasing the use of agricultural crops as feedstock for biofuels (specifically biomass and starch from corn for ethanol; and vegetable oils and animal fats and their derivatives for biodiesel, extenders and additives).

**Projects: ($7,090,316 Net to Location - ERRC):**

1. Improving the Economic Competitiveness of Ethanol Production -
Devise and exploit commercial process efficiencies for the production of ethanol from corn to reduce the selling price of fuel ethanol. Lower process costs and develop valuable co-products which reduce the net price of ethanol feedstocks.

2. New Biobased Products to Increase Demand for Grains -
Develop new valuable products and processes for the conversion of corn and other grain into food and industrial products that reduce end-product cost to consumers and increase revenues to growers and rural processors.

3. New Processes for Obtaining Higher Value-added Products from Agricultural Lipids -
New processing technologies based upon biocatalysis and/or biomimetric reagents are developed for converting animal fats and vegetable oils into value-added products. Targeted areas include: harvesting industrially important fatty acids from fats and oils; restructuring of natural glycerides; producing biodiesel and biobased fuel additives and lubricants, industrial biopolymers, and oxygenated and branched chain materials from agronomic glycerides.

4. Sustainable Technologies for Polysaccharide-Based Functional Foods and Biobased Products -
Develop and utilize new physical, biocatalytic and molecular technologies for the efficient and sustainable ("green") extraction and modification of plant polysaccharides to create new biobased industrial products, functional food ingredients and high valued nutraceuticals.

5. Bioconversion of Agricultural Fats, Oils and their Derivatives Into Value-added Biopolymers -
Develop a cost effective process for production of biodegradable polymers from agricultural fats and oils. Specific goals include: 1) identify microbial strains capable of the biotransformation of triglyceride feedstocks into biodegradable polymers; 2) genetically manipulate these strains to achieve high-level synthesis; 3) develop high-yield fermentation processes; and 4) characterize products for commercial applications.

6. Processing Treatments to Improve the Physical and Chemical Properties of Leather and Wool -
Improve the mechanical attributes of leather and the processability of wool in its blend with cotton and other cellulosic fibers.

7. Modification of Pre-tanning Processing to Reduce Environmental Impact and Improve Hide Quality -
Improve the competitive position of the domestic tanning industry by reducing the cost of environmental compliance through modification of pre-tanning processes and by working with the domestic animal livestock industry and the packing industry to improve domestic hide quality.

8. Investigation of Biocatalytic Methods for Tanning Processors -
Develop biocatalytic tanning methods that would greatly reduce the need for chromium and organic crosslinking agents and to chemo-enzymatically modify leather byproducts for use as filling or processing agents that will improve the uniformity and quality of finished leather.

**Research Area Descriptions**

1. Biobased Products
   - Pre-fermentation separation of valuable co-products, e.g., zein
   - Oxygenated fat derivatives by biocatalysis, e.g., castor oil alternatives
   - Structural lipids by lipase enzymology
   - Valuable fatty acids from common fats and oils using lipase enzymology
   - Lubricant additives from fats and oils
   - Enzyme bioreactors for conversion of commodity fats and oils
   - Biodegradable polymers (Polyhydroxyalkanoates) and surfactants (Sophorolipids) from fermentation of fats and oils
   - Crosslink collagen and gelatin using transglutaminase catalysis for quality leather
   - Oxidative extraction of valuable hemicellulose gums from corn fiber
   - Develop "green" extraction processes using supercritical fluids and high temperature/pressure ethanol

for extraction of nutraceutical oils, natural pesticides, industrial oils and sunscreens from grain brans.
  - Develop valuable coproducts from grain and stover-to-ethanol processes by chemical, enzymatic and physical methods

2. Biofuels
   - Reduce energy required for downstream ethanol separations
   - Model ethanol process operations and costs to develop cost-effective technologies
   - Produce biodiesel from alternative feedstocks (fat, restaurant grease, soapstock)
   - Develop facile technology for monitoring the quality of biodiesel

**Unique Facilities**

Among its many research resources, ERRC has a Biochemical Engineering Pilot Plant, including fermentors of 10 L to 300 L, and separations-support equipment, Small-scale Corn Wet Milling Facility and Pilot Plant, Food, Dairy and Cheese Processing Pilot Plants, Biological Safety Level (BL)2 Fruits and Vegetable Engineering Pilot Plant, Hides to Leather Tannery Pilot Plant, and Industrial Pilot Plant. All are equipped for scale-up studies, pilot scale processing, or testing of theoretical concepts. Engineering process design studies including optimization and cost analysis are conducted by a cost engineer and use of ASPEN™, a computer simulation package. State of the art instrumentation for GC/MS, LC/MS, HPLC are available. Advanced Accelerated Solvent Extraction systems, preparative supercritical fluid extractors, twin screw extruders, Perceptive Biosystems BioCad Perfusion Chromatography Workstation, Bioreactors, Advanced Microwave Reactor System and Rheometrics Dynamic Mechanical Testing apparatus are also available. A Core Technologies Unit coordinates state-of-the-art computer networking and molecular modeling capabilities, microscopic imaging-conventional scanning electron microscopy, confocal laser scanning optical microscope system, high resolution scanning-transmission electron microscope, magnetic resonance spectroscopy and a nucleic acid sequencing operation with a Perkin-Elmer 3700 DNA Sequencer, all fully operational and staffed with research support personnel.

**Expertise**

The ERRC has 26 permanent research scientists and engineers working on biobased products and biofuels. These researchers work on a variety of multidisciplinary projects within the Center and with other national and international Federal, state and local government laboratories, as well as industrial, academic and small business partners for fundamental, applied and development research on agricultural commodities. Collectively, the expertise is on protein, carbohydrate and lipid chemistry, analytical chemistry, applied enzymology, plant physiology, physical chemistry, food science, biochemistry, microbiology, molecular biology and chemical, biochemical, mechanical and cost engineering. These researchers have published hundreds of peer reviewed articles, hold numerous patents and have been selected for many awards and honors by scholarly organizations, institutions and professional societies.

**Collaborations**

The ERRC has a strong record of transferring technology to stakeholders and developing research programs, based on input from industry, and action-regulatory agencies. Actions include: identify-contact potential users, develop Collaborative Research and Development Agreements (CRADA), Confidentiality Agreements, Memorandum-of-Understandings, Trust Fund Projects, Specific Cooperative Agreements, etc., license patents and respond to technological needs of stakeholders.

**Interagency Cooperative Studies**

Among the many collaborations ERRC has with Federal, state, local agencies, academia, industry, etc., the following is an important example relative to this DOE, USDA and EPA Strategic Partnership

Workshop, April 11-12, 2001. The USDA's ERRC and Department of Energy, National Renewable Energy Laboratory have two active collaborative research projects to do comparative studies. One is modeling the process to produce ethanol from corn and produce ethanol from cellulosic material, corn stover, and to identify the major economic factors associated with each process. A second study is identifying and quantifying fine chemicals, phytosterols, tocopherol and sterol glucosides, in stover and residues from stover-to-ethanol production processes. Estimate value and production costs for these coproducts are being determined.

# Research Capabilities: USDA-ARS Forage Research, Lincoln, NE

## A. Research Area:

Development of Switchgrass into a Biomass Energy Crop for the Midwest.

## B. Introduction:

The USDA-ARS forage and range project at Lincoln, NE has been conducting research on switchgrass as a pasture and range species since the late 1930's. Unit scientists began cooperating with DOE in 1990 via a Reimbursable Agreement on developing switchgrass into a biomass fuel crop for the Midwest. The objectives of the project are to develop improved cultivars and management practices for switchgrass grown as a biomass fuel crop in the region. The project has been expanded several times and currently includes research on breeding and genetics, management, feedstock quality, economics, and soil quality including carbon sequestration. The research involves cooperative research with the University of Wisconsin, University of Nebraska, South Dakota State University, and ARS at Mandan, ND. Specific Cooperative Agreements have been established with the Universities. On farm trials were initiated in 2000 in Nebraska and will be expanded to South and North Dakota in 2001. This project has been ARS's principal project to date on the development of perennial biomass energy crops.

## C. Specific Description of Research Efforts:

Breeding and genetics: Germplasm evaluation, basic genetic studies on switchgrass, development of conventional cultivars, technology development for production of hybrid cultivars, cultivar and experimental strain evaluation as bioenergy crops.
Management research areas: Improved assays for seed quality, improved establishment, improved weed control during establishment, fertility management, harvest management.
Feedstock quality: Determine feedstock quality as affected by cultivars and field and harvest management. Includes development of improved methodology.
Field scale production and economics: Initiated field scale on-farm trials in 2000 with farmer cooperators. Data collected will be used in economic analysis by cooperating economists.
Carbon sequestration research: Research being conducted in cooperation with other USDA-ARS, USDA-NRCS and University cooperators.

## D. Unique facilities:

Project has the capability to conduct switchgrass field research throughout the Midwest and has laboratory equipment to do comprehensive feedstock quality research.

## E. Expertise relevant to research area:

Laboratory has 5 permanent FTE's ( 2 SY's), 1 Post-doc, and 2 additional support staff. It has formal cooperating arrangements with 22 SY's at six other laboratories or locations.

## F. Collaborations essential to research area:

Oak Ridge National Laboratory , DOE. Funding and multi-disciplinary interactions.
Univ. of Nebraska-Lincoln. Field and Laboratory support; Cooperative research on seed quality, management, economics.
Univ. of Wisconsin-Madison. Breeding and genetics research for the Northern Midwest.
South Dakota State University. Conservation Reserve Program land management for biomass, soil carbon sequestration, breeding for semi-arid regions of Great Plains.
USDA-ARS, Mandan, ND. Management, cultivar evaluation, soil carbon.
USDA-ARS, Ft. Collins, CO. Soil carbon and carbon sequestration.
USDA-NRCS, Lincoln, NE. Soil carbon and carbon sequestration and on-farm trials.

**US Department of Agriculture-Agricultural Research Service**
**Soil and Water Conservation Research Unit**

**A. Descriptive Title of Research Area**

Soil and Crop Management Research - The Soil and Water Conservation Research Unit (SWCRU) of the Agricultural Research Service (USDA-ARS), and its processor, have been conducting research on crop and soil management practices for 60 years with the broad objective of developing or improving technologies that protect the environment and promote sustainable, integrated production systems by: 1) Developing improved technologies that protect surface and ground water from contamination by nutrients, sediments, and manure-borne pathogens; 2) Identifying soil and crop indicators of cropping system sustainability; and 3) Disseminating knowledge and information to stakeholders in the form of management tools, publications, and decision aids. Currently we have nine scientists and 25 support staff (support scientists, post docs, and technicians) conducting research on these objectives. Contacts should be directed to:


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|---|---|
| Wally Wilhelm or Jim Schepers | 402-472-1514 (phone) |
| USDA-ARS | 402-472-0516 (FAX) |
| 120 Keim Hall-UNL | wwilhelm1@unl.edu |
| Lincoln, Nebraska 68583-0934 | jschepers1@unl.edu |


Details on all research capabilities, current projects, and contact information for all members of the Research Unit are available on our website (http://www.ianr.unl.edu/arslincoln/swcru/home.htm).

B. Specific descriptions of research efforts in this research area – We have field, laboratory, and greenhouse facilities to investigate the impact of crop and soil management practices on crop productivity and soil quality. Several existing research sites have more than 10 years of continuous application of treatments to study the long-term affect of various production practices (tillage, crop sequence, N-fertilizer application, crop residue removal) on biomass production, grain yield, soil carbon content, and soil erosion. Other current research activities include developing remote sensing equipment and tools to help growers apply site-specific management practices to crops and soil, developing decision aids for application of site-specific management, evaluating use of livestock manures as source of N and P for crops, developing methods for assessing soil health, and assessing the impact of crop residue removal on soil organic C content and crop productivity. In addition facilities are available to initiate new study to investigate the affects of new management strategies on crop and soil productivity and quality.

# C.Unique facilities –

Long-term experiments

Tillage/Rotation – This experiment to study the impact of tillage (plow, disk, chisel, subsoil, no tillage, and ridge tillage) in combination with crop sequence (continuous corn, continuous soybean, and corn/soybean rotation) was initiated in 1980 and has had continuous application of treatment and a 20+-year record for crop grain and biomass production and soil characteristics.

Rotation/N fertilization – The interaction of continuous cropping and two- and four-year crop rotations with corn, soybean, sorghum, and oat-clover and rate of N-fertilizer application has been documented for over 25 years. This long-term record of cultural practice impact on biomass and grain yield and soil characteristics (bulk density, soil carbon, soil N distribution, etc.) is one of the oldest currently active cropping systems research sites in the nation.

Crop rotation/Cultivar/N fertilizer – This irrigated study was initiated in 1990 to devise new soil management and crop production practices that reduce nitrate leaching to ground water from corn production fields. It includes treatments of crop rotation (continuous corn, continuous soybean, and corn/soybean rotation), corn and soybean cultivar, and N-fertilizer rate. This site is currently used to develop remote sensing and site-specific management technologies.

Site-Specific Management – We have developed, and continue to refine, several tools to assist landowners and crop managers apply cultural practices to the crop or soil in a site-specific manner. These tools allow assessment of soil limitations or crop stress on a time- and space-specific basis. We continue to investigate ways to allow growers to correct these limitations and stresses in specific areas of fields.

Soil Erosion and Runoff – Portable and laboratory equipment is available to assess soil and crop management practice influence on soil and runoff.

Prediction of Biomass Production – Expertise to estimate or calculate biomass production over time and space.

E. Expertise relevant to research area

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|---|---|
| Crop Management: | Strong capability |
| Soil Management: | Strong capability |
| Site-specific crop management (Precise agriculture): | Capability |
| Soil erosion and runoff: | Interest |
| N management: | Capability |
| Soil quality assessment: | Capability |
| Soil organic matter (organic C) assessment and management: | Capability |
| Remote sensing: | Capability |
| Geographic information systems (GIS) | Capability |

F. Collaborations essential to research area

University of Nebraska: Provides services

# WESTERN REGIONAL RESEARCH CENTER

**United States Department of Agriculture**
**Pacific West Area, Albany, CA 94710**
**www.pw.usda.gov**
**James N. Seiber, Ph.D., Center Director**
**510-559-5600; jseiber@pw.usda.gov**

The **Western Regional Research Center** is part of a USDA site in Albany, CA, which also features:

- *The Plant Gene Expression Center (http://www.pgec.usda.gov/ ), which conducts fundamental research in plant molecular biology,*
- *The Pacific West Area Office, the ARS administrators for the Pacific West Area, and*
- *The U.S. Forest Service's Southwest Pacific Research Station.*

The **Western Regional Research Center (WRRC)** is a multidisciplinary regional center housing **80 full time Scientists and over 140 Support Personnel**. It is one of four USDA Regional Centers, which were originally established by Congress in 1938 to improve and **expand commodity utilization**. Although research on utilization of agricultural commodities and products continues to be a mainstay of the Center, research on other contemporary issues such as **food safety, crop improvement, and biological control of agricultural pests** has been added to the Center's research portfolio.

| UNIT | CONTACT | CONTACT INFO |
|---|---|---|
| WRRC Center Director's Office | James N. Seiber, Center Director | 510-559-5600 jseiber@pw.usda.gov |
| Technology Transfer | Martha Steinbock, Tech Transfer Coordinator | 510-559-5641 mbs@pw.usda.gov |
| Cereal Product Utilization (CPU) | Pamela Keagy, Research Leader | 510-559-5650 keagy@pw.usda.gov |
| Process Chemistry & Engineering (PCE) | George Robertson, Research Leader | 510-559-5621 grobertson@pw.usda.gov |
| Crop Improvement & Utilization (CIU) | William Hurkman, Research Leader | 510-559-5750 bhurkman@pw.usda.gov |
| Food Safety & Health (FSH) | Robert Mandrell, Research Leader | 510-559-5610 mandrell@pw.usda.gov |
| Plant Protection Research (PPR) | Bruce Campbell, Research Leader | 510-559-5800 bcc@pw.usda.gov |
| Exotic & Invasive Weeds (EIW) | Raymond Carruthers, Research Leader | 510-559-6127 ric@pw.usda.gov |

**WRRC Mission:**

The Western Regional Research Center conducts mission-oriented research **to enhance the healthfulness of foods; to develop new and novel food and industrial products from renewable resources; and to protect and enhance the quality of the environment.** The results of these research efforts are implemented through the effective transfer of new and innovative technologies to appropriate clients and users. WRRC goals are as follows:

A. ***To enhance healthfulness of foods*** by creating crop plants and food products that promote health, productivity and quality of life and by developing systems and methods that ensure the safety of the food supply.

B. ***To develop new and novel food and industrial products*** from renewable resources using biotechnology to develop improved tailored agricultural crops and bioengineering to create new products from agricultural crops and processing co-products.

C. ***To protect and enhance the quality*** of the environment by developing sound and sustainable systems for efficient food and industrial processes.

D. To ensure the effective ***transfer of new and innovative technologies*** by integrating technology transfer into program and project design and developing private and public partnerships

**WRRC Competencies**

I. Biofuels

**A. Separation and directed enzymology:**

**B.** The Biofuels research team consists of >10 FTE's with a clear capability in grain separation techniques, **directed enzymatic evolution**, **polysaccharide liquefaction**, **fermentation technologies, and polysaccharide development**. The lead scientists in these areas each have more than 15 years experience in their respective fields. Contact: George Robertson, Research Leader, Process Chemistry & Engineering (PCE), 510-559-5866; grobertson@pw.usda.gov

**C. Research Direction:**

**Directed molecular evolution of amylase enzymes** and cold hydrolysis

The conversion of grain-derived starch to glucose syrups as a source of sweeteners and a raw material for fermentation to ethanol and other higher-valued products requires the application of cooking and enzymatic hydrolysis to liquefy and saccharify the starch. **Enzymes produced by directed molecular evolution (1) reduce energy consumption during conversion by lowering temperatures, (2) reduce chemical consumption by optimizing pH ranges in each step, and (3) reduce capital expenditure for cookers and reaction vessels by working effectively at lower temperature.** Directed molecular evolution targets a "parent" enzyme with specific activity towards starch (wheat starch in this case), creates large libraries of randomly modified enzymes, and screens optimal molecules from this library. The screening and randomization, which are applied recursively, evolve molecules to successfully and rapidly hydrolyze cold, unliquified starch. **At present, this recursive selection process has resulted in amylases with 80 fold higher efficacy than their parent enzymes.**

**Solvent displacement technologies for wheat pretreatment**

This project **reduces the environmental impact of conventional milling/separation processes and improves the efficiency of grain fractionation**. Conventional "washing" fractionation employs water to wash wheat starch away from hydrated and developed flour dough, thereby removing water-soluble proteins. The protein fraction (gluten) produced by water washing is about 75-80% pure and extremely difficult to dry. Successful research has led to the invention of a process in which ethanol, a fast-drying organic solvent, is used in the washing process. Separation is comparable in yield and concentration to that of water washing.

Significant benefits are that ethanol maintains protein quality at "vital" levels and that the resulting protein is more easily and rapidly dried. **This solvent process is expected to significantly reduce the energy demand in drying and capital cost.**

D. **Unique Facilities**:

*food pilot plant, lab-scale and pilot-scale fluidized bed reactors, computer-controlled press.*

E. **Expertise**:

*Grain separation technology*

*Optimal usage of grain streams*

*Development of novel polysaccharides,*

*Amylase enzyme technology.*

## II. Biobased Products:

**A. Polymer conversion technologies**

B. Wheat production in the U.S. is nearly double what is needed for domestic consumption. The wheat surplus has typically been sold in unstable foreign markets; however, finding new non-food uses for this surplus would certainly benefit American farmers. **The mission of this project is to develop non-food products from wheat starch, wheat straw, rice straw and other agriculturally derived waste fiber streams**. This project has 10 FTE's and has been actively growing for 9 years. Contacts include Gregory Glenn, Project Lead (510-559-5677; gmg@pw.usda.gov), and Pamela Keagy, Research Leader, CPU (510-559-5650; Keagy@pw.usda.gov).

**C. Research Direction:**

Much of the research of this "Biopolymer" project has focused on developing new starch products, such as **starch-derived biodegradable packaging, lightweight starch-based concrete, and "environmentally-friendly" polysaccharide soil additives to replace polyacrylamides**. Wheat starch, along with wheat straw fibers and wheat straw fillers are used to make degradable **hamburger "clamshells**" that keep food warmer than the cardboard and paper wraps currently used. A large fast food restaurant is testing the starch-based packages developed in this project. The success of this project hinges on characterization of the unique physical and chemical properties of wheat starch, modified starch, and blends of starch with other components, and using this characterization knowledge so that these materials can fill market niches.

D. **Unique Facilities**:

Industrial-grade and pilot-scale polymer processing equipment: *industrial-scale cup-molder, a compression molding extruder, a compounding extruder, pilot-scale twin-screw processing extruders, film forming/stretching capabilities.*

Instruments: *SEM, MALDITOF, DSC, GPC, FTIR, TGA, NMR, Instron, X-ray diffraction analysis, permeability, rheology*

E. **Expertise**:

*polymer characterization*

*polymer processing*

*utilization of agriculturally derived biopolymers.*

F. Partners:

**Industrial partners and growers groups** have joined in collaboration with the present researchers to aid in commercialization. They include **Tenneco Packaging, Penford Starch, Inc., Lundberg Family Farms, and the Washington, Idaho and Oregon Wheat Commissions.**

## III. Crop Biotechnology

A. **Tailored crop resources (Castor, Guayule, and Wheat):**

B. WRRC has a very strong capability in using **biotechnology to improve crops including castor, guayule, and cereal grains, particularly wheat cultivars**, with >25 FTE's. Research on castor is led by Tom McKeon (520-559-5754, tmckeon@pw.usda.gov), guayule is led by Katrina Cornish (559-5950, kcornish@pw.usda.gov, and wheat is led by **Olin D. Anderson** (510-559-5773, oandersn@pw.usda.gov; http://wheat.pw.usda.gov/homepage/) has grown tremendously in the past 10 years.

C. **Research Direction:**

**Castor for Biobased oil-seed products**

Castor bean produces a unique oil with up to 90% of the fatty acid content as ricinoleate. Castor oil and products derived from it are used for numerous bio-based products, including lubricants, paints, coatings, plastics and antifungals. **Castor has been genetically modified to eliminate toxic factors**. Toxic factors including ricin and allergenic storage proteins have inhibited the use of this crop.

**Guayule for hypoallergenic and other rubber products**

Guayule can be a domestic source of natural rubber products including **hypoallergenic products (surgical appliances, gloves) as well products important to defense and transportation**. Research at WRRC has identified processing methods and improved crop varieties to make cultivation and utilization of this desert shrub a reality. Implementation would reduce or eliminate dependence on foreign imports.

**Wheat improvement**

The specific objectives of this project are to improve wheat crop outputs, as well as to develop cultivars that **produce novel protein and starch outputs, such as modified gluten-like proteins**. An interesting offshoot of this research is the development and maintenance of **computer databases on small grains** (wheat, barley, rye, oats), sugarcane, and related grasses. This is part of the **USDA's Plant Genome Project**, which includes computer databases on the genetics of the major crop species. The goal of the program is to provide rapid distribution of genetic information for use in creating enhanced crop varieties. The project collaborates with researchers throughout the U.S. and internationally in the assembly and analysis of genetic data relating to crop improvement. In addition, the project assists in the development and distribution of DNA markers for genetic research on the small grains and for improved crops.

D. **Unique Facilities**:

USDA's Plant Genome Project, which includes computer databases on the genetics of the major crop species (see http://wheat.pw.usda.gov/homepage/). Plant Comparative genomics Facility, ABI 3700 DNA Sequencers (3), Affymetrix Microarray Station, Q-Bot Robotics Station.

E. **Expertise**:

As mentioned above, WRRC and its USDA sister lab at Albany, the Plant Gene Expression Center (http://www.pgec.usda.gov/ ) maintain a very strong capability in crop biotechnology, with >25FTE's. **Comparative genomics, Wheat sequencing & bioinformatics, Genetic biotechnology of multiple cereal crops**

F. **Partners**:

These projects collaborate with researchers throughout the U.S. and internationally in the assembly and **analysis of genetic data relating to crop improvement**. In addition, the project assists in the development and distribution **of DNA markers for genetic research on the small grains and for improved crops**.

# USDA Forest Service
# Forest Products Laboratory
# Research Capabilities

For more than 90 years, the USDA Forest Service, Forest Products Laboratory (FPL), has provided the science and technology needed to maintain and extend the Nation's forest resources. Work is concentrated in a single location to focus research expertise and promote an interdisciplinary approach to solving a wide spectrum of wood utilization problems. The FPL has approximately 250 employees, including scientists and technicians. It is the only national laboratory serving this purpose and is recognized both nationally and internationally as an unbiased technical authority on wood science and use.

**Key Contact**: Susan L. LeVan 608-231-9518, slevan@fs.fed.us.

**FPL website**: www.fpl.fs.fed.us

## Research Area Descriptions

***Advanced Housing Research.*** FPL is a world leader in housing-related research, particularly in areas such as engineered wood products and structures, moisture and indoor air quality, material design and performance, coatings and finishes, adhesives, wood preservation, biodeterioration, and wood/nonwood composites. The goal of this research is to accelerate the widespread use of advanced housing technologies that improve the quality, durability, environmental performance, energy efficiency, and affordability of our Nation's housing.

***Biobased Products and Energy***. Biobased product and bioenergy technologies have the potential to make sustainable forest resources a major source of chemicals, liquid fuel, pharmaceuticals, and an array of other biobased materials and products. The FPL has the scientific expertise and core research programs to rapidly contribute by developing the technologies needed to (1) produce chemicals, pharmaceuticals, and new materials from wood; (2) produce ethanol fuels and feedstock from wood; (3) use low-valued material for value-added forest products; and (4) assess the economic potential of short-rotation woody crops for a variety of new uses.

***Environmental Technologies***. Environmental technologies help conserve forest timber and fiber resources and mitigate environmental problems associated with production, conversion, use, and disposal of forest products. FPL research is helping to develop new technologies such as (1) models and accounting methods to determine and predict the amount of carbon stored in forest products as well as anticipated carbon emission or storage impacts; (2) biopulping technologies to reduce energy requirements in thermo-mechanical pulping processes; (3) non-chlorine bleaching systems using polyoxometalates, which can be recovered and oxidized for repeated use; (4) new technologies to overcome the technical barriers to recycling printing and writing grades of paper; (5) reducing the production of volatile organic compounds from wood-based materials during processing; and (6) biotechnology techniques that improve paper and wood processing at reduced costs.

***Water Quality***. FPL research is aimed at improving the quality of drinking water—either through purification through low cost wood fiber filters or through new processing techniques that eliminate contamination of our water. One area of research focuses on eliminating the use of toxic chemicals in preservative treatments of wood. A second area focuses on eliminating or reducing production and discharge of hydrocarbons into rivers and streams. A third area focuses on low cost, efficient, fiber-based water-filtering technologies to remove organic and inorganic toxic materials, pesticides, and herbicides from both point and non-point sources.

***Value-Added Uses of Small-Diameter Trees***. FPL research is focusing on developing value-added uses for small-diameter trees. The driving force for this effort is the vast amount of small-diameter trees that are contributing to a significant fire risk in the West. FPL research is aimed at developing the technologies that help overcome the technical and economic barriers associated with creating value-added uses. For example, research projects are exploring the potential of small-diameter trees used in pulp and papermaking; studying the use of roundwood as a structural material for bridges, boardwalks, trail structures, picnic shelters, storage sheds, and other buildings; and evaluating the distribution of lumber grades from small-diameter material.

Unique Facilities

The FPL has dependent on state-of-the-art facilities for testing and evaluation. The following facilities are available at FPL:

- Engineering mechanics laboratory to test and evaluate engineering properties
- Pilot plant for pulping and paper making, including refiners, digesters, and paper machine
- Analytical chemistry laboratory to analyze wood chemistry, including mass spec, NMR, HPLC, GC
- Paper testing laboratory to evaluate properties of pulp and paper
- Composite laboratory, including blenders, extruders, presses
- Fire laboratory for fire testing of material properties
- Preservative treatment facilities
- Dry kilns
- Test frame to test full-size houses
- Adhesive laboratories

Expertise

FPL has 75 scientists working in these various areas. Their expertise includes biologists, plant pathologists, mycologists, biochemists, microbiologists, wood anatomists, chemists, chemical/mechanical/structural engineers, and forest products technologists. The FPL cooperates regularly with universities, industry, and federal and state agencies to develop and implement technologies that will ensure the long-term sustainability of forests and forest-based economies.

## USDA Forest Service
## North Central Research Station Capabilities

### In Woody Bioenergy Crop Development

Fast growing trees in intensively managed plantations can provide an energy source that does not contribute to increased atmospheric $CO_2$, can augment fiber supplies, can reduce harvest pressure on natural forests, and can improve the environment. All these benefits can be achieved while trees simultaneously contribute to rural economic development as an alternative agricultural crop. The North Central Research Station has a long-standing research program on intensive forestry systems. This research has

- Identifed hybrid poplar clones that exceed current commercial clones in growth rate by as much as 100%.
- Sustained traditional wood products industries and reduced pressure on natural forests for fiber production,
- Made intensive plantation management an economically viable enterprise.

In partnership with the Department of Energy, Oak Ridge National Laboratory, Biofuels Feedstock development Program and other collaborators, we are designing and conducting breeding and selection programs to produce new crop tree genotypes. We are also developing the silvicultural systems needed to realize the genetic potential of the new genotypes. This project typifies the interagency partnerships that we form to accomplish our research objectives and maximize the effectiveness and productivity of our program.
Primary Contact: Don E. Riemenschneider (driemenschneider@fs.fed.us)
NCRS website: http://www.ncrs.fs.fed.us

**Research Area Descriptions**

Intensive forestry systems require fast growing trees that are pest resistant and possess other desirable characteristics such as ease of propagation. We develop these trees through our breeding research accomplished in cooperation with the Minnesota Hybrid Poplar Research Cooperative and other organizations. Strategies include production of new inter-specific $F_1$ hybrids, improved populations of native cottonwood, and production of advanced generation populations. Selection criteria include growth, disease resistance, rooting ability, and wood quality. We are developing a genomic map of one of our hybrid populations in collaboration with ORNL.

The genetic and silvicultural elements required for the successful establishment of intensive forestry systems are necessary but not sufficient to guarantee the long-term sustainability of those systems We consider sustainability issues in our R&D Programs to determine how elements of the production system interact within the ecological context of the system. For example, hybrid poplar plantations represent a simplified above-ground ecological system. Weeds are controlled by vegetation management strategies that we develop. Damaging insects are controlled by chemical or biological pesticides. Above-ground biomass growth is relatively easy to estimate, as is the above-ground contribution to carbon sequestration. In comparison, relatively little or nothing is known about the complexity of the below-ground physiology of hybrid poplar crop trees, especially regarding rates of biomass (and carbon) accumulation, rates of respiration, and the role of below-ground growth patterns relative to crop genotype or management practice. We are beginning to study these below-ground phenomena on a genome basis in collaboration with ORNL.

**Unique Facilities for Crop Development Research**

North Central Research Station is a multi-state R&D organization with several field laboratories in addition to laboratories at Station Headquarters in St. Paul, MN. NCRS maintains a network of Experimental Forests and test sites where genetics and silvicultural studies ranging from natural forest silviculture to intensive plantation management are conducted. NCRS operates fully equipped laboratories that support research in diverse areas, including: the assessment of forestry's social dimension, disease and pathogen biology and biotechnology, integrated insect management and control, landscape ecology and trend assessment, evaluation of potential climate change effects, below-ground ecology, genetics, tree improvement, and tree biotechnology.

**Expertise relevant to Bioenergy Crop Development**

North Central Research Station has a long history in the development of woody bioenergy crops. Short Rotation Intensive Culture (SRIC) of hybrid poplars was first developed in the United States at the Rhinelander Forestry Sciences Laboratory beginning in 1970. NCRS possesses scientific expertise in the area of breeding, quantitative genetics, vegetation management and the physiology of tree growth and development. This expertise is absolutely required to develop productive woody crops. NCRS additionally possesses scientific expertise in the disciplines of insect and disease management, above and below-ground ecology, silviculture, economics and the social sciences, all of which are required to maintain plantations as sustainable biomass-producing strategies. NCRS should be classed as "capable" with between 9 and 24 FTEs committed.

**Collaboarations Essential to Crop Development Capability**

Crop development research is undertaken by USDA-FS, North Central Research Station as part of a multidisciplinary, multiagency integrated research effort. Most research projects at NCRS collaborate within the Station as part of three Integrated Research and Development Programs. Additionally, extramural collaborations that are essential for the conduct of significant R&D programs in the area of woody crop development are maintained with:

US DOE ORNL BFDP/ESD

University of Minnesota

Minnesota Agr. and Utilization Res. Inst.

Iowa State University

University of Wisconsin

Michigan State University

Michigan Tech. University

Blandin Corporation (UPM)

Boise Cascade

Minnesota Power and Light

Potlatch Corporation