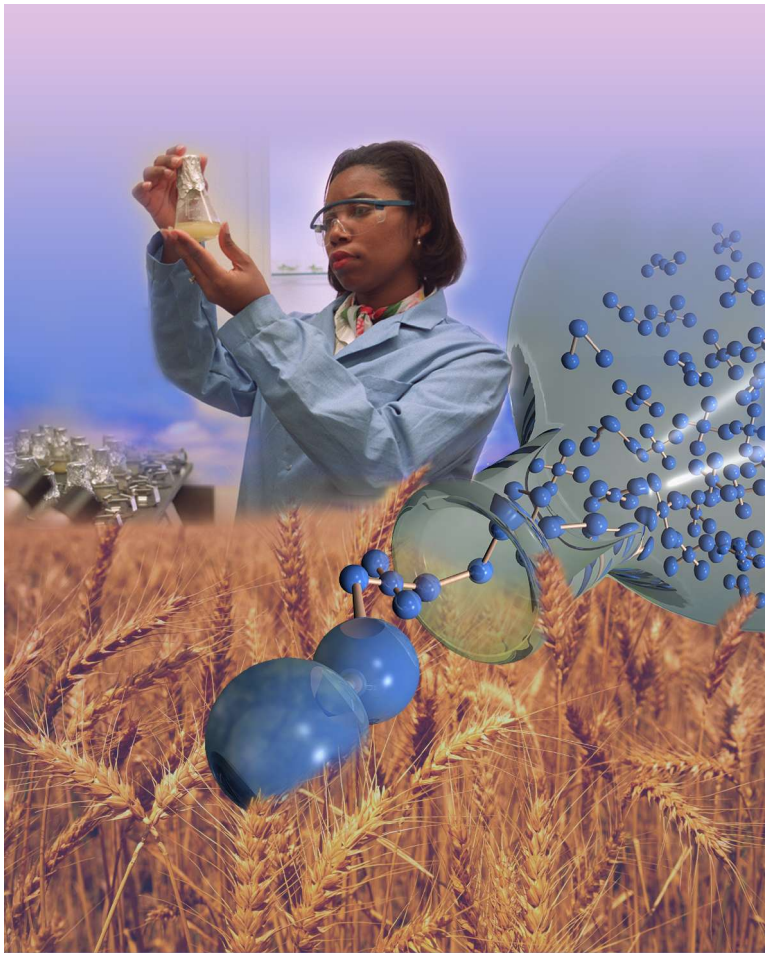
Western Regional Capabilities in Plant/Crop-Based Renewable Resources



February 2003

Prepared for the U.S. Department of Energy

Preface

A consortium of land-grant universities and federal laboratories has conducted an assessment of the Western Regional R&D capabilities in the area of bio-based products and bioenergy.* The consortium included the Pacific Northwest National Laboratory (PNNL), Idaho National Engineering and Environmental Laboratory (INEEL), Washington State University (WSU), University of Idaho (UI), and University of California, Davis (UCD). The Western Regional Agricultural Research Service (WRARS) also participated.

The overall goal of this work was to provide the U.S. Department of Energy (DOE) an integrated summary of the capabilities related to the former** Office of Industrial Technologies' (OIT) Strategy and Roadmap documents in this area and to assist in the progress toward the DOE vision:

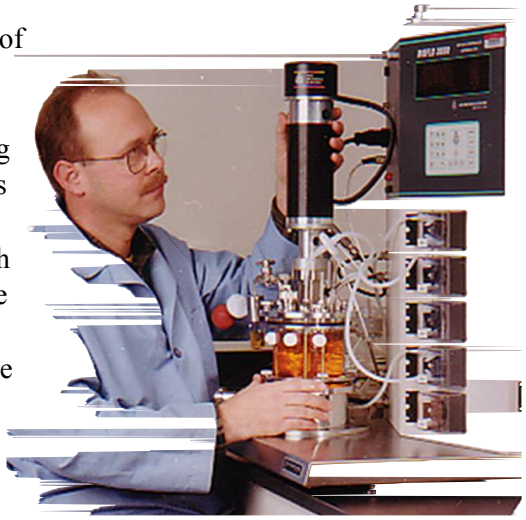
"to provide continued economic growth, healthy standards of living, and strong national security through the development of plant crop-based renewable resources"

*This report serves as the Final Report for:PNNL Field Work Proposal 43889 and INEEL Field Work Proposal 4C5-0

**During the course of this project a significant restructure occurred at DOE and the initial DOE Roadmap was revised. Consultation with representatives of the DOE Office of Biomass led to the decision to complete the tasks and prepare the final report.

Executive Summary

The overall goal of this work was to provide DOE with an integrated summary of the Western Region capabilities related to the former Office of Industrial Technologies' (OIT) Strategy and Roadmap documents. The initial focus of the project was to map the Western Region's capabilities to the DOE Roadmap, included in this report as Appendix A. The analysis consisted of the identification of detailed, capabilities of the regional labs and universities and the identification of areas where those R&D capabilities can be used to assist DOE in bridging existing knowledge gaps. The participants in this project were the Pacific Northwest National Laboratory (PNNL), Idaho National Engineering and Environmental Laboratory (INEEL), Washington State University (WSU), University of Idaho (UI), and University of California, Davis (UCD). The Western Regional Agricultural Research Service (WRARS) also participated.



The capabilities of the Western Region span the entire scope of the initial DOE Roadmap, i.e., Plant Science, Production, Conversion, and Utilization. The Universities and the Western Regional Research Center (WRRC) have outstanding research programs in Plant Science; the National Laboratories have complementary programs in Production, Conversion, and Utilization. The current DOE guidance regarding research objectives focuses on two platforms within Conversion. In the more narrowly defined Roadmap, biomass conversion was divided into the Sugars Platform and the Syngas platform. The opportunities within these areas of research include new approaches to the development of sugars from biomass and the conversion of biomass to fuel. The Western Region has unique research institutions capable of performing the interdisciplinary work required to discover, develop and deploy new technology in this area. Several of these research institutions are committed to working together as demonstrated by the creation of the Northwest Bioproducts Research Institute. A technology focus employing an interdisciplinary approach, rather than a regional focus has been identified as more likely to achieve long term biomass conversion goals.

Much of the research required to develop economical processes to convert biomass to fuel or to convert biomass to sugars for fuel and chemicals involves the development of the next generation of Biorefinery Microbes. The new microbes must be developed as integral components of complex biomass conversion processes involving novel collection technology, integrated biological and chemical conversions to sugars, chemical and fuel. This report shows that the Western Region has the capabilities and committed institutions to make significant contributions in this area.

Contents

1.0 Introduction

The former Office of Industrial Technologies' (OIT) in the Department of Energy (DOE) requested a report on the capabilities of the Western Region as it related to DOE's draft Bioenergy and Bioproducts Roadmap. This report contains five parts, an Introduction, a Summary Table: Western Regional Capabilities Mapped to the Roadmap, a description of the NWBRI, Conclusions and two appendices. Appendix A containis the DOE's initial Bioenergy Roadmap as a reference for the Summary Table and Appendix B is a computer disc containing a database of all the information gathered from each participating organization.

The Western Regional Consortium included the Pacific Northwest National Laboratory (PNNL), Idaho National Engineering and Environmental Laboratory (INEEL), Washington State University (WSU), University of Idaho (UI), and University of California, Davis (UCD). The Western Regional Agricultural Research Service (WRARS) also participated. Four of the participants in this project have formed the Northwest Bioproducts Research Institute (NWBRI). This was identified as one of the Western Region's valuable resources.

The initial focus of the project was to map the Western Region's capabilities to the DOE Roadmap, included in this report as Appendix A. The analysis consisted of the identification of detailed, capabilities of the regional labs and universities and the identification of areas where those R&D capabilities can be used to assist DOE in bridging existing knowledge gaps. This was completed in late 2002.

In the initial meeting at Washington State University, participants refined the work plan and agreed upon a more detailed outline for the capabilities project and data to be gathered. The initial efforts focused on compiling the technical capabilities of individuals in the participating organizations. Preliminary information was compiled by each organization and distributed to others for review. A second project meeting was held at University of Idaho. Participants reviewed progress and identified other areas for additional effort. Due to the volume and complexity of the information, use of an electronic database was proposed and accepted as the format for the final report and it is included as Appendix B. During the course of this project a significant restructuring occurred at DOE and the initial DOE Roadmap was revised. The final two meetings of the project team, held at Washington State University and INEEL, addressed the final report structure and content in regard to the revised DOE Roadmap. Consultation with representatives of the DOE Office of Biomass led to the decision to complete the tasks and prepare the final report. Consistent with the primary task the capabilities are mapped to the initial DOE Roadmap.

The Western Region has many assets; the institutions participating in this project are among those assets. Each of the participating institutions is described below.

1.1 Idaho National Engineering and Environmental Laboratory (INEEL)

INEEL embraces the vision of "Whole Crop Utilization" and leverages key multidisciplinary capabilities to address the major science and technology needs associated with the cost-effective utilization of waste biomass. Besides promoting use of agricultural biomass to produce energy, fuels, chemicals, and durable goods, the Whole Crop Utilization concept has the added advantage of revitalizing rural economies by providing an additional revenue source to growers. INEEL, in partnership with Inland Northwest Research Alliance (INRA) universities and with industry, is investigating and developing methods to overcome key barriers to cost-effective utilization of crop residuals and forestry wastes for energy, fuels, and chemicals production.

1.2 Pacific Northwest National Laboratory (PNNL)

PNNL, operated by Battelle, has established ongoing programs to support the DOE biomass to fuels and energy objectives. The research on thermo-chemical conversion of biomass to chemicals began more than 20 years ago. Recently, this effort has been expanded as the Bio-based Products Initiative, a program to integrate the PNNL expertise catalyst design and catalytic conversion with biological process development. The process development research focuses on filamentous fungi, an underutilized group of microorganisms known to be involved in biomass conversion in Nature. The strategy is to find and develop new fungi to produce products by fermentation that can be converted to value-added chemicals using PNNL's chemical catalysis technology. A unique attribute of this work is the integrated team; chemists and biologists working together. The approach involves working with industrial partners and universities, and leveraging the world-class instrumentation available at PNNL to achieve the ultimate objective – substantial reduction in the use of petroleum.

1.3 University of Idaho (UI)

UI programs in bioproducts and biofuels research range from molecular manipulation to create plants with unique characteristics to engine performance testing programs with ethanol and biodiesel. Research is focused not only on biofuels, but on the development of value-added products that complement the bioenergy research. The programs benefit from the presence of strong programs in plant science, soil science, entomology, plant pathology, agronomy, forestry, and agricultural engineering. The University has the expertise available to develop new crops, optimize their agronomic performance, harvest and process the biomaterials to produce fuel, and test the performance of such fuels in a variety of engines. Examples of such an integrated approach are reflected in its existing Center for Clean Vehicle Technology and ongoing efforts to develop a Bioenergy Farm for biomass conversion and industrial product development.

1.4 Washington State University (WSU)

WSU is a comprehensive land-grant university. Chartered in 1890, the University conducts education, research, and outreach activities to benefit the state, region, and nation. WSU has established itself as a leader in plant science, agronomy, wood material and engineering, and biorefinery. Those research efforts are conducted in the Institute of Biological Chemistry, in the Wood Material and Engineering Laboratory, in the Center for Multiphase Environmental Research, and in other programs at the University, including the Agriculture Research Center, the Biological Systems Engineering Department, and the Chemical Engineering Department.

The Institute for Biological Chemistry is known for plant biochemistry and physiology study. The Graduate Program in Plant Physiology is generally recognized as one of the "top 10" in the world and is a preeminent graduate program at WSU. The focus of their research is on plant metabolism and molecular and cellular biology, and on integrating new discoveries that relate plant biochemistry to the unique constraints that shape plant growth, development, and evolution. Current projects include biochemistry and control of lignin metabolism, photosynthetic process regulation, plant metabolic engineering for enhanced productivity, etc.

The Wood Materials and Engineering Laboratory (WMEL) is an interdisciplinary research facility administered through the College of Engineering and Architecture. The WMEL has received international acclaim during its long history spanning five decades of research in collaboration with

industry, government agencies, and other universities. They develop new building materials from a range of recycled and virgin resources. They also develop innovative structural systems to effectively utilize new materials while maintaining economic viability and public safety. The laboratory is accredited by the International Congress of Building Officials (ICBO), and can conduct products testing, characterization, and performance evaluation.

The Center for Multiphase Environmental Research (CMER) was established during the 1996-1997 academic year. CMER is also a 1999 grant recipient of the National Science Foundation Integrative Graduate Education and Research Training Program. A Bioresource Utilization Laboratory was established at CMER. Center faculties from the Biological Systems Engineering Department are working together with researchers from industry and government agencies to obtain value-added bio-based products from agriculture residues. Research activities cover raw materials pretreatment, fermentation, cellulase production, separation, and process integration. Current projects include value-added chemicals from animal manures, and process optimization for lactic acid production from cull potatoes.

WSU has a strong and established research reputation in agronomy. It is ranked among the top six in the U.S. in natural resource economics. Among the areas of greatest strength are resource economics, agricultural marketing and trade, production economics, regional economics, and econometrics. In addition, WSU also has a Cooperative Extension Energy Program to extend the results of research and scientific expertise to the people of Washington State and beyond. A nationally recognized staff conducts research, develops tools, and disseminates information to aid in energy-related decision-making.

1.5 Western Regional Agricultural Research Center (WRARS) at Albany, CA

WRARS as a USDA research center, this laboratory has a long history of research on a variety of agricultural topics. The emphasis for many years has been on important biomass crops, including wheat. Research programs have included fundamental research on enzyme cloning and engineering to the development of commercial applications of agricultural crop residues.

1.6 California Institute of Food and Agricultural Research (CIFAR) at the University of California, Davis (UCD)

The University of California Davis is one of the largest and most renowned centers of higher education in the world. Started in 1908 as the University Farm, today UC Davis is an acknowledged international leader in a wide array of disciplines. It is among the most academically diverse of the nation's leading public universities. It's research and extension programs serve the needs of California and the nation in agricultural, environmental and human science while preserving and enhancing environmental and human resources.

CIFAR was established to create opportunities for research collaboration and technology exchange between UC Davis and the food and agricultural industries. Making connections between UCD and the State as well as the Western Region to promote renewable crop based research has included work on the discovery and development of enzymes for biomass conversion.

2.0 Western Regional Capabilities Mapped to "THE TECHNOLOGYROADMAP FOR PLANT/CROP-BASED RENEWABLE RESOURCES 2020

Each institution has provided information on researchers and research groups and their work in the relevant areas defined in the initial DOE Roadmap developed. This work is summarized in the table below. Part of this capability assessment was to develop a database linking individuals and their capabilities with roadmap categories. This searchable relational database will serve as a resource for DOE and the NWBRI and its members. The database is included in the compact disk (CD) appended to the back cover of this report. The CD also contains spreadsheets and reports detailing the current contents of the database.

Summary of Western Regional Capabilities

	INEEL	PNNL	UCD	UI	WRARS	WSU
Plant Science/Raw Material Development						
Genomics	✓	✓	✓		✓	✓
Plant Breeding			✓	✓		✓
Plant Adaptation	✓	✓	✓			✓
Production						
Harvesting	✓		✓	✓		
Collecting	✓		✓	✓		
Handling	✓		✓	✓		✓
Storage	✓		✓	✓		✓
Transportation	✓		✓	✓		
Agronomy	✓			✓		✓
Conversion						
Pretreatment	✓	✓	✓	✓	✓	✓
Conversion - Biological	✓	✓	✓	✓	✓	✓
Conversion - Catalytic/Thermal		✓		✓		✓
Separation/Purification	✓	✓	✓	✓		✓
Process Integration		✓	✓			✓
Utilization						
Product Testing	✓		✓	✓	✓	✓
Characterization		✓	✓	✓	✓	✓
Performance Evaluation		✓	✓	✓		✓
Product Development		✓	✓	✓		✓

3.0. Western Capabilities Mapped to the Current Office of Biomass Focus

A significant requirement for meeting the DOE goals for reducing reliance on petroleum is the development new biomass conversion technology. Conversion of biomass to sugars, chemicals and fuel has been defined as falling into two categories: the Sugars Platform and the Syngas Platform. The table below shows that the Western Region has capabilities in this area of research.

	INEEL	PNNL	UCD	UI	WRARS	WSU
Sugars and Syngas Platforms						
Biomass Preparation	✓	✓	✓	✓	✓	✓
Conversion - Biological	✓	✓	✓	✓	✓	✓
Conversion - Catalytic/Thermal		✓		✓		✓
Separation/Purification	✓	✓	✓	✓		✓
Process Integration		✓	✓			✓

Part of the research required for economical processes to convert biomass to fuel or to convert biomass to sugars for fuel and chemicals involves the development of the next generation of Biorefinery Microbes. The new microbes must be developed as integral components of complex biomass conversion processes involving novel collection technology, integrated biological and chemical catalytic conversions to sugars, chemical and fuel.

It is clear that successful research and development in this area will require the collaboration of many different research institutions. In the Western Region collaborative activities are already in place and will serve as a foundation on which future collaborative programs can be built. The Northwest Bioproducts Research Institute is an example of the commitment in the Western Region to promote such collaboration .

4.0 Northwest Bioproducts Research Institute

The Northwest Bioproducts Research Institute (NWBRI) conducts multi-disciplinary research in various topics related to the use of agricultural materials to create high value products (such as pharmaceuticals, specialty chemicals, and commodity chemicals) and energy. The Institute provides the model for engaging and enlisting industry and trade group advisory members and others in prioritizing the R&D needs. NWBRI's Advisory Board is composed of select members with bioproducts expertise from academia, national labs, and industry and trade groups. This broad-based perspective provides guidance regarding critical regional and national needs.

Northwest Bioproducts Research Institute offers:

- Multidisciplinary approach
- Extensive network of expert research capabilities
- State-of-the-art facilities and equipment

4.1 Goals of NWBRI

The goals of NWBRI are first to create improved technologies needed to build the bioproducts/energy industry and to develop a large and influential collaborative research and development program in bio-based products. A further goal is to coordinate educational and training opportunities to provide the

technical personnel required to sustain the bioproducts/energy industry. The NWBRI has identified the development of the next generation of microbes and integrated bioprocess for the Biorefinery as a priority.

4.2 Structure of the NWBRI

- An Executive Committee, composed of a top executive from each of the founder institutions, , INEEL, PNNL, UI, and WSU manages the Institute through an Executive Director serving as the Chair of the Operating Committee/Technical Working Group composed of representatives from all participating organizations.

- The Bioproducts Advisory Committee identifies R&D needs, objectives, and priorities and will make recommendations on specific R&D efforts.

- The Bioproducts Advisory Committee consists of members from regional industry, growers, and environmental groups, as well as selective representation from national industry and growers groups.

- The Institute plans include a multi-user, research and test facility in Richland, Washington, to facilitate the development of the "biorefinery" concept. A complementing facility at Idaho Falls, Idaho, will focus on crop production and the technologies necessary to optimally collect, transport, and store the biomass feedstocks.

4.2 General Benefit to DOE

- The Institute provides the framework for the integration of capabilities, including those of the industrial partners, to establish a unique bioprocessing research center.

- The region produces an exceptionally wide range of products (grains, fruits and vegetables, forage crops, dairy products, forest products, and many others), demanding integrated and flexible solutions to biomass processing for products and energy.

- The technology created and demonstrated will have wider applications than just regional interests, thus contributing to the nation's desire to increase markets for agriculture and reduce dependence on imported petroleum.

- The Institute combines unique expertise in the areas of biotechnology, production technology, economic/market analysis, and agricultural/food science to create a nationally renowned capability in the production of valuable products from agricultural materials

- The focus of the research is on rapid reduction to practice by integrating the technologies into a complete system, from crop production to processing in a "biorefinery."

4.3 Benefit to the Office of Biomass

Much of the research required to develop economical processes to convert biomass to fuel or to convert biomass to sugars for fuel and chemicals involves the development of the next generation of Biorefinery

Microbes. The new microbes and new technology must be developed as integral components of complex biomass conversion processes involving novel collection technology, integrated biological and chemical conversions to sugars, chemical and fuel. The following are examples of relevant collaborative research already in place.

PNNL has several projects in place in the area of direct biomass conversion. PNNL and WSU are collaborating on a project to identify new technology for converting manure to chemicals and energy. Proprietary catalytic conversion technology is being applied to the conversion of biomass to new value-added products. Research on gasification technologies for conversion of renewable biomass to energy and chemicals is a significant component of the work at PNNL. To support the Biorefinery concept, INEEL and PNNL are collaborating with industry to develop technology to make new chemicals from low value by-products of dry mill ethanol plants. A unique and essential component of the research at PNNL is the integration of chemical catalysis, biochemistry, genetics, and process development research. Internal programs at PNNL include the discovery of new enzymes for conversion of biomass using filamentous fungi. Filamentous fungi are being targeted as a part of the Bio-based Products Initiative to develop platform microbes for converting biomass to value-added products, such as organic acids. Thermo-chemical approaches to biomass conversion have been developed at PNNL for more than 20 years.

INEEL has developed a broad range of programs and expertise in support of the Bioenergy Initiative. Current research includes collaborations with both university and private industry partners. Research into the single pass, multi-component harvester is progressing rapidly. Recent work has begun to focus on the the biological pretreatment of straw using white-rot fungus. Work has also commenced in the development of an enzymatic pretreatment system for crop residues using thermo-stable hemicellulases and the development of bacterial extremophiles for bioconversion processes.

UI maintains strong programs in the development of new crops and the modification of existing crops through both traditional breeding and cutting-edge molecular techniques. . Efforts in processing and conversion have been focused on conversion technologies, including enzymatic biodegradation and biotransformation of lignin, ethanol production from agricultural waste materials, and lactic acid production from food processing waste. Forest products research includes the development of composite materials, bio-based polymers as thermoplastic resins, and non-wood specialty chemicals Biofuels research ranges from developing improved methods of biodiesel and ethanol production to fuel testing in various types of engines and vehicles.

WSU has bioproduct research related expertise that crosses several colleges and many departments. The Wood Materials and Engineering Laboratory has received international acclaim during its five decades of research in developing new building materials from a range of recycled and virgin resources. The laboratory is accredited by the International Congress of Building Officials, and also can conduct products testing, characterization, and performance evaluation. The Bioresource Utilization Laboratory is collaborating with industry and government laboratories to develop processes to develop value-added bio-based products from agriculture residues. Research activities cover raw materials pretreatment, fermentation, cellulase production, separation, and process integration.

5.0 Conclusions

The Western Region's DOE laboratories, Agricultural Research Services (ARS), and land-grant universities have capabilities in 8 out of 10 categories in the DOE's draft Bioenergy and Bioproducts Roadmap. The capabilities of the Western Region span the entire scope of the initial DOE Roadmap, i.e., Plant Science, Production, Conversion, and Utilization. The Universities and the WRRC have outstanding research programs in Plant Science; the National Laboratories have complementary programs in Production, Conversion, and Utilization.

At DOE evaluation of the initial Roadmap has continued and the Roadmap has been refined and focused. The more narrowly defined Roadmap focuses on Conversion and has defined two areas of research: These have been identified as the Sugar Platform and the Syngas.Platform. Opportunities within these areas of research include the development of biomass conversion to sugars and biomass to fuels and chemicals. The research required is the development of the next generation of Biorefinery microbes (biocatalysts) and other catalytic processes.

Research programs are already in place to explore extremophilic bacteria (INEEL) and the filamentous fungi (PNNL). This work complements and extends the work on yeast and acidophillic bacteria in progress at other national laboratories. At WSU and UCD, world-renown institutes, The Institute of Biological Chemistry and The California Institute of Agriculture and Food Research, are conducting ongoing research on the genetics, biochemistry, and molecular biology of microorganisms. At UI and WSU, there are ongoing programs in the Engineering and Agricultural Department on biological processes involving microorganisms. Both Universities have long-standing programs with the USDA laboratory in Albany, California. The Northwest Bioproducts Research Intitute, operating under an unique agreement that brings several Western Region research institutions together to create improved technologies needed to build the bioproducts/energy industry and to develop a large and influential collaborative research and development program in bio-based products.

To achieve the goals for displacing petroleum through the increased use of renewable biomass, rapid development of the next generation of microorganisms for the Biorefinery is essential. The next generation of microbes will have to use variable feedstocks, operate in more extreme environments, and be very efficient and productive. The unique contribution of the Western Region will be in the development of novel biotechnology that is integral to feasible commercial processes. The NWBRI has identified the development of the next generation of microbes and bioprocesses for the biorefinery as a priority. It is NWBRI's view that the development of this novel technology will serve regional and national interests.

Appendix A:

Western Regional Capabilities Mapped to "THE TECHNOLOGY ROADMAP FOR PLANT/CROP-BASED RENEWABLE RESOURCES 2020

Appendix B:

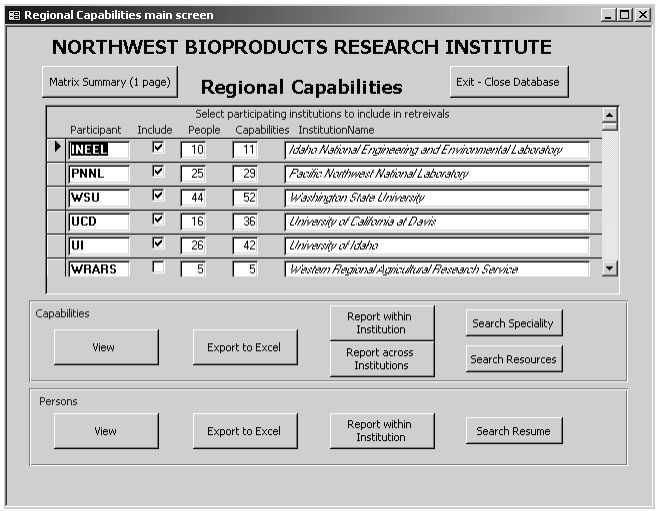
Western Regional Capabilities in Plant/Crop-Based Renewable Resources Database

Instructions for use of Compact Disk

The CD-ROM appended to this report contains a database and reports that summarize the capabilities of the participants in the Northwest Bioproducts Research Institute. The CD is designed for Windows 95/98/NT/ME/2000/XP users. The database requires Microsoft Access 2000. There is a file on the CD named "Readme.txt" that describes the contents and provides detailed instructions.

To start the CD-ROM using Windows, follow these steps:

1. **Insert the CD-ROM into your computer's CD drive.**
2. **Launch Windows Explorer.**
3. **Click Browse to browse the CD.**
4. **Locate and print the reports and spreadsheets if you wish.**
5. **To activate the database, highlight the file named "RegionalCapabilities.mdb" and double-click.**



Files on the CD:

Readme.txt - detailed instructions as ASCII text document.

RegionalCapabilities.mdb – MS Access 2000 database with self explanatory user interface.

Capabilities.xls – MS Excel 2000 workbook containing 171 rows, columns A – Z.

People.xls – MS Excel 2000 workbook containing 122 rows, columns A – Q.

Capability Matrix sorted by Partner.pdf – Adobe Acrobat report containing 55 pages.

Capability Matrix sorted by Technology and Capability.pdf – Adobe Acrobat report containing 46 pages.

Capability Matrix Summary.pdf – Adobe Acrobat report containing 1 page.

Persons.pdf – Adobe Acrobat report containing 194 pages.