



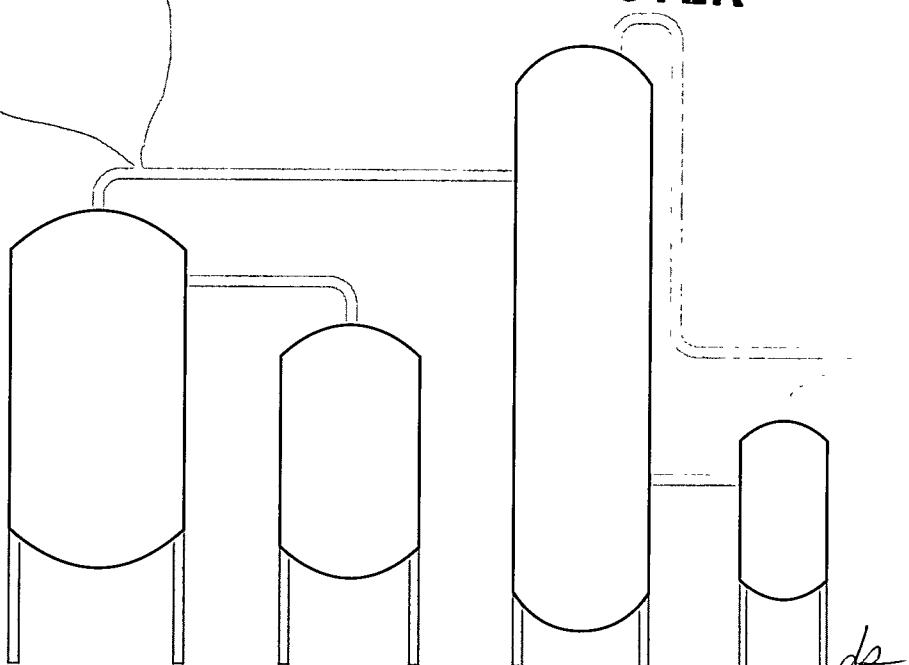
Biofuels: 1995 Project Summaries



MASTER

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Table of Contents

	Page
Preface	ix
Ethanol	1
Pretreatment	3
Alternate Pretreatment Study—Ammonia Recycled Percolation	4
Kinetic and Modeling Investigation of Dilute-Acid Pretreatment	5
Alternate Pretreatment Study—Dilute Acid and Organosolv	6
Installation, Shakedown, and Operation of NREL Pretreatment Reactors	7
Optimization of Dilute-Acid Pretreatment of Selected Biomass Feedstocks	8
Pretreatment of Lignocellulosic Materials by Pressure Cooking in Water	9
Alternate Pretreatment Study—Lime Pretreatment	10
Identify Inhibitory Components in Dilute-Acid Pretreated Lignocellulosic Biomass	11
Alternate Pretreatment Study—Alkaline Peroxide Extrusion	12
Cofermentation Biocatalyst Development	13
Cofermentation Process Development	14
Demonstrate Direct Microbial Conversion (DMC) Process	15
Continuous Bioreactors for Conversion of Paper Sludge to Ethanol	16
Pentose Sugar Transport in <i>Zymomonas</i>	17
Evaluate Inoculum Preparation Techniques for Cellulose Conversion to Ethanol	18
Cofermentation Medium for <i>Zymomonas</i>	19
Genetic Engineering of Xylose-Fermenting Yeasts	20
Cellulase Development	21
Fungal Cellulases	22
Cellulase Structure	23
Cellulases from <i>Thermomonospora fusca</i>	24
Cellulases from <i>Clostridium thermocellum</i>	25
Cellulases from <i>Microbispora bispora</i>	26
Cellulases from <i>Thermotoga neapolitana</i>	27

Table of Contents (continued)

	Page
Ethanol (continued)	
Compositional Analysis of Biomass Samples	28
Develop and Maintain Project QA/QC Program	29
Analyze Complex Samples and Develop Methods	30
Process Integration	31
Process Development Unit (PDU)	32
Feedstock Shredding, Storage, and Delivery in Support of the Process Development Unit (PDU) and Feedstock Knife Milling and Handling in Support of the Biofuels Program	33
Biodiesel	35
Project Management, Market Development, and Public Outreach for Biodiesel	37
New Process Options for Biodiesel Conversion and Glycerol Utilization	38
CO ₂ Mitigation in Fossil Fueled Power Plants Using Microalgae with Coproduction of Biodiesel	39
Existing Technology Options for Production of Biodiesel from Low-Cost Feedstocks	40
Life-Cycle Assessment of Biodiesel	41
Genetic Transformation of Microalgae for Enhanced Production of Natural Oils as a Feedstock for Biodiesel	42
Biochemistry and Metabolic Engineering of Microalgae for Enhanced Biodiesel Production	43
Isolation of a Polyubiquitin Gene Promoter for Expression of Foreign Genes in Microalgae	44
Biosyngas	45
Biosyngas Product: Synthesis Research	47
Biosyngas Product: Catalyst Development	48
Biosyngas Products: Gasifier Stream Characterization	49
Biosyngas Products: Refinery Feedstock Research—Microactivity Test	50
Biosyngas Products: Thermochemical Process Development Unit (TCPDU)	51
Biosyngas Products: Thermochemical PDU Analytical Support	52
Biosyngas Products: Indirectly Heated Biomass Gasifier—Phase 2	53
Biosyngas Products: Carbon Catalyzed Gasification of Organic Compounds	54
Biosyngas Products: Gasification Products Characterization and Conditioning	55

Table of Contents (continued)

	Page
Biocrude	57
BioCrude Products: Process Screening	59
BioCrude Products: Tetrahydrofurfuryl Alcohols and Tetrahydrofurfuryl Ethers	60
BioCrude Products: Hazen Operations	61
BioCrude Products: Alternative Processes—Novel Ethers	62
BioCrude Products: Biocrude-Derived Diesel	63
BioCrude Products: TCPDU Engineering and Experimental Design	64
BioCrude Products: Conversion of Lignins to Reformulated Gasoline	65
Biofuels Feedstock Interface	67
Feedstock Interface	69
Stakeholder Communications	70
Feedstock Services and Interface	71
Market Analysis on Near-Term Sources of Biomass Feedstocks	72
Biomass Resource Assessment	73
Standards Development and Rapid Analysis	74
Feedstock Assessment	75
Feedstock Quality Model	76
Thermochemical Conversion and Rapid Analysis	77
Effects of Storage on Eucalyptus	78
Dilute Acid Pretreatment and Simultaneous Saccharification and Fermentation (SSF) of Hybrid Poplar and Switchgrass	79
Innovative Research for the Harvesting, Handling, Processing, and Storage of Sorghum	80
Effects of Ambient Environment on the Storage of Switchgrass in Iowa for Biomass-to-Ethanol and Thermochemical Projects	81
Preparation of Briefing Book of New Industrial Uses for Agricultural Commodities	82

Table of Contents (continued)

	Page
Biofuels Feedstock Interface (continued)	
Seedling-to-Tailpipe Model	83
Effects of Storage on Hybrid Poplar (DN34)	84
Study of the Opportunities and Barriers to the Implementation and Sustainability of Bioenergy Systems	85
Effects of Ambient Environment on the Storage of Switchgrass in Texas for Biomass-to-Ethanol and Thermochemical Projects	86
Effects of Ambient Environment on the Storage of Switchgrass in Kentucky for Biomass-to-Ethanol and Thermochemical Projects	87
Effects of Ambient Environment on the Storage of Switchgrass in Virginia for Biomass-to-Ethanol and Thermochemical Projects	88
Energy System Geographic Mapping for the State of Wisconsin	89
Technical Evaluation and Planning	91
Biofuels Strategic Plan	93
International Energy Agency Bioenergy Agreement	94
Screening Study for Sawmill Waste Biomass-to-Ethanol Production Facility	95
Preliminary Feasibility Analysis for Collocating Cellulosic Ethanol Plants with Biomass Power Facilities	96
Biomass Systems Integration Program	97
Economic Development through Biomass System Integration in Central Florida	98
New Bern Biomass to Energy Project	99
Feasibility of Reducing Costs of Liquid Fuels and Electricity from Dedicated Biomass Feedstocks and Waste-to-Resource Management	100
Strategic Planning for the Biofuels Systems Program	101
Information Management Assessment and Quality Improvement	102
Information Management Systems	103
International Energy Agency Bioenergy Strategic Plan	104
The Role of the Regional Biomass Energy Program in Methane Recovery	105
Biomass Methanol	106

Table of Contents (continued)

	Page
Technical Evaluation and Planning (continued)	
Feasibility Analysis: Transition from Grain to Cellulose-Ethanol	107
Planning, Progress, and Issue Analysis	108
Biofuels Feedstock Development	109
Analysis of Feedstock Production and Environmental Systems in DOE Feasibility Studies	111
Baseline Soils Study for the 1000-Acre Hybrid Poplar Energy Crop Demonstration Project	112
Bioenergy from Willow	113
Biochemical Basis of Drought Tolerance in Hybrid <i>Populus</i> Grown under Field Production Conditions	114
Bird and Small Mammal Use of Hybrid Poplar Plantings in Minnesota	115
Breeding Bird Use of Hybrid Poplar and Switchgrass Plantings	116
Cumulative Surface Water Effects	117
Development of <i>in vitro</i> Culture Systems for Switchgrass (<i>Panicum virgatum</i>)	118
Effects of Herbaceous and Woody Energy Crops on Uptake, Release and Off-Site Movement of Nutrients and Pesticides	119
Energy Crop Data and Information Management	120
The Environmental Effects of Biomass Crop Development Conference	121
Evaluation of Genetic Selection Criteria for <i>Populus</i> Clones	122
Farm-Level Issue Analysis	123
Genetic Improvement and Evaluation of Black Cottonwood for Short-Rotation Biomass Production	124
Genetic Variation among Switchgrass for Agronomic Traits, Forage Quality, and Biomass Fuels Production	125
Harvesting Initiatives	126
Minnesota Wood Energy Scale-Up Project	127
Optimal Establishment and Cultural Practices for Switchgrass as an Energy Crop in the Southeastern United States	128
Poplar Molecular Genetics Cooperative	129
<i>Populus</i> Crop Development in the Southeast United States	130

Table of Contents (continued)

	Page
Biofuels Feedstock Development (continued)	
Productivity Research of Switchgrass (<i>Panicum virgatum</i>)	131
Regional-Scale Integrated Modeling System to Evaluate the Potential Cost and Supply of Biomass from Energy Crops	132
Regional Testing of <i>Populus</i> Clones	133
Selection and Breeding of Pest-Resistant Clones of <i>Populus</i> for Biomass Energy Production in the North Central United States	134
Selection and Breeding of New Switchgrass (<i>Panicum virgatum</i>) Varieties for Increased Biomass Production	135
<i>Septoria</i> Pathosystem Studies for <i>Populus</i>	136
Short-Rotation Forest Plantations in Brazil	137
Switchgrass as a Biofuels Crop for the Upper Southeast: Variety Trials and Cultural Improvements	138
Switchgrass Cultivars and Cultural Methods for Biomass Production in the South Central United States	139
Tree Genetic Engineering Research Cooperative	140
Bibliography (Arranged by Project)	141
Bibliography (Arranged by Author)	159
Index of Current Contractors	173

Preface

Domestic transportation fuels are derived primarily from petroleum and account for about two-thirds of the petroleum consumption in the United States. In 1994, more than 40% of our petroleum was imported. That percentage is likely to increase, as the Middle East has about 75% of the world's oil reserves, but the United States has only about 5%. Because we rely so heavily on oil (and because we currently have no suitable substitutes for petroleum-based transportation fuels), we are strategically and economically vulnerable to disruptions in the fuel supply. Additionally, we must consider the effects of petroleum use on the environment.

The Biofuels Systems Division (BSD) is part of the U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EE). The day-to-day research activities, which address these issues, are managed by the National Renewable Energy Laboratory in Golden, Colorado, and Oak Ridge National Laboratory in Oak Ridge, Tennessee. BSD focuses its research on biofuels—liquid and gaseous fuels made from renewable domestic crops—and aggressively pursues new methods for domestically producing, recovering, and converting the feedstocks to produce the fuels economically.

The biomass resources include forage grasses, oil seeds, short-rotation woody crops, agricultural and forestry residues, algae, and certain industrial and municipal waste streams. The resulting fuels include ethanol, methanol, biodiesel, and ethers.

BSD's goal is to develop technologies that make biofuels economically competitive with and environmentally superior to fossil fuels. This is consistent with the Energy Policy Act of 1992, the 1988 Alternative Motor Fuels Act, and the Clean Air Act Amendments of 1990.

To commercialize these fuels, BSD has formulated a strategy that provides for:

- The technology base for the private sector to increase sustainable supplies of biomass feedstocks suitable for economic conversion processes
- The technology base for the thermochemical and biochemical conversion of biomass feedstocks to liquid fuels

- The early transfer of technology to private industry by involving industry in cost-shared projects that will verify the technical feasibility and environmental benefits of biofuels technologies.

DOE, in partnership with the nation's industrial and agricultural sectors, continues to develop an extensive biofuels knowledge base that helps researchers identify technical barriers to cost competitiveness, determine priorities among the viable biofuels research options, and increase the marketability of biofuels. This collaborative research will continue to help build a strong U.S. biofuels industry, increase our economic competitiveness, reduce our dependence on foreign oil, and maintain our environmental integrity.

The project summary sheets in this volume account for the research sponsored by DOE BSD during FY 1994 and FY 1995 (October 1, 1993 through September 30, 1995). Each sheet contains information on project funding, objectives, approach, accomplishments, and status. Significant publications are in two bibliographies at the back of the book: one is organized according to project, the other by primary author.

Ethanol

Pretreatment

Directing Organization:

U.S. Department of Energy (DOE)
1000 Independence Avenue, SW
Washington, DC 20585

Project Manager: J. Mielenz

Telephone: (303) 275-4489

Contractor:

National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Principal Investigator: R. Elander

Telephone: (303) 275-4430

Contract Number: DE-AC02-83CH10093

Contract Period: 10/94-9/95

Contract Funding (Source):

FY 1993: \$340,532 (DOE)
FY 1994: \$252,000 (DOE)
FY 1995: \$302,000 (DOE)

Objective:

Develop efficient, cost-effective pretreatment techniques for preparing enzymatically digestible lignocellulosic biomass and fermentable soluble sugar prehydrolyzates.

Approach/Background:

Cellulose in lignocellulosic biomass is not readily digestible by cellulase enzymes; a pretreatment step is necessary to render it digestible. Dilute acid pretreatment techniques also solubilize the hemicellulose fraction of biomass to (primarily) pentose sugars, which are then available for subsequent fermentation to ethanol. Preliminary results of a two-stage, dilute-acid pretreatment scheme that use a percolation process show that, in addition to generating more highly digestible pretreated solids residues, yields of xylose equivalents are significantly increased. Further information about the fermentability of the hemicellulose-based sugars in prehydrolyzates, which may require toxic compounds to be removed from the breakdown of other biomass components before fermentation, is needed. A firm understanding of key reaction parameters and mass-transfer effects is necessary to begin considering reactor design options for large-scale processes.

Status/Accomplishments:

Larger bench-scale percolation reactor systems were brought on-line to generate larger quantities of pretreated biomass.

The two-stage, dilute-acid percolation pretreatment work was expanded to additional feedstocks, including hardwood sawdust. A factorial-design experimental approach was used to collect data to develop improved reaction conditions for maximizing the enzymatic digestibility of pretreated sawdust.

Kinetic modeling studies identified the countercurrent contacting of solids and liquor as the most efficient mode for optimizing dilute-acid, flow-through pretreatment systems. Process engineering evaluations indicated which key operating parameters of the flow-through pretreatment system need to be modified to maximize the beneficial effects of this type of pretreatment in the context of the overall biomass-to-ethanol process.

Initial contacts were made with prospective equipment vendors who can provide large-scale countercurrent pretreatment reactors, and preliminary equipment budget information has been obtained.

Major Project Reports: See bibliography.

Summary Date: September 1995

Alternate Pretreatment Study— Ammonia Recycled Percolation

Directing Organization:

U.S. Department of Energy (DOE)
through the
National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Project Manager: J. Mielenz

Telephone: (303) 275-4489

Contractor:

Auburn University
Auburn, AL 36849

Principal Investigator: Y.Y. Lee

Telephone: (334) 844-2019

Contract Numbers: XAW-3-11181-02;
XAW-4-14170-01

Contract Period: 1/93–8/95

Contract Funding (Source):

FY 1993: \$114,422 (DOE)
FY 1994: \$168,334 (DOE)

Objective:

Identify and develop pretreatment approaches that can improve ethanol production process performance and cost over the NREL base-case dilute sulfuric acid pretreatment process.

Approach/Background:

Pretreating lignocellulosic biomass is a key step in a successful biomass-to-ethanol conversion process. Until 1992, resources were focused on a dilute sulfuric acid pretreatment process, which has become part of the NREL base-case ethanol process. The process has several areas for improvement. This subcontract is one of several established to conduct research and development on other promising pretreatment processes. Ammonia recycled percolation (ARP) pretreatment has not yet been reported in the literature.

Status/Accomplishments:

We studied the ARP pretreatment process and established near-optimum conditions for milled whole-tree hybrid poplar, switchgrass, and a corn stover/corn cobs mixture. Hybrid poplar delignified as much as 50%, the corn stover/corn cobs mixture 80%, and switchgrass 85%. Concomitantly, hemicellulose was removed by 50%–60% for all three

feedstocks. Solids pretreated were highly digestible. The ARP process was readily adaptable to SSF for ethanol production. Toxicity tests of the pretreatment effluents, after removing ammonia and precipitating lignin, showed that as much as 60% strength of the effluents could be used without significant adverse fermentation effects. Material balance on ammonia showed that the ammonia consumption was 0.02g NH₃/g dry biomass. The process generated sulfur- and sodium-free lignin that could become a valuable by-product.

To increase the fractionation of xylan and lignin, a pretreatment scheme that uses autohydrolysis (hot-water treatment), dilute-acid percolation, or hydrogen peroxide treatment before the ARP, was explored. The additional pretreatment step before the ARP process showed enhanced hemicellulose removal and recovery, and increased the extent of delignification, which showed the possibility of fractionating biomass almost completely.

Major Project Reports: See bibliography.

Summary Date: September 1995

Kinetic and Modeling Investigation of Dilute-Acid Pretreatment

Directing Organization:

U.S. Department of Energy (DOE)
through the
National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Project Manager: J. Mielenz

Telephone: (303) 275-4489

Contractor:

Auburn University
Auburn, AL 36849

Principal Investigator: Y.Y. Lee

Telephone: (334) 844-2019

Contract Number: XAW-3-13441-01

Contract Period: 7/91-2/96

Contract Funding (Source):

FY 1992: \$113,361 (DOE)

FY 1993: \$109,646 (DOE)

FY 1994: \$126,330 (DOE)

FY 1995: \$103,820 (DOE)

Objective:

Understand the effects of operating variables on yields of xylose from hemicellulose in NREL's two-stage dilute sulfuric acid pretreatment process and provide analytical support to NREL in-house and subcontracted research staff to chemically analyze biomass samples.

Approach/Background:

When lignocellulosic biomass is pretreated, hemicellulosic sugars (primarily xylose) are released. We can determine the relationship between particle size, temperature, residence time, acid concentration, and xylose yield by conducting experimental and modeling studies. This study uses hybrid poplar, yellow poplar, switchgrass, and corn stover to establish kinetic models that predict yields of xylose through dilute sulfuric acid pretreatment. By incorporating the obtained kinetic models, process operating models that describe a two-stage, reverse-flow percolation process can be developed and simulated to give the optimum operating conditions. Up-flow percolation reactor configurations that account for intraparticle and interparticle mass and heat transfer phenomena, are being investigated.

Status/Accomplishments:

We developed kinetic models that describe the release of xylose and oligomeric xylose during dilute-acid pretreatment. These models, based on experimental data and theoretical kinetic analysis, demonstrate that the use of a two-stage pretreatment scheme allows for variable temperature profiles that greatly enhance the process performance. The models dealt with four percolation reactor configurations, and gave the best performing reactor configuration.

Work is ongoing to improve the process operating models by incorporating the generation of oligomeric xylose as an intermediate product, mass and heat diffusion factors, and nonideal flow characteristics to more accurately predict dilute-acid pretreatment process performance. As oligomeric xylose is received as an intermediate product, secondary hydrolysis of converting oligomer to its monomer by temperature holdup and enzyme were investigated, and the best conditions of the secondary hydrolysis determined.

The kinetic work on dilute-acid pretreatment and hydrolysis of yellow poplar that employ extremely dilute acid is ongoing.

Analytical service to NREL in-house and subcontracted research personnel was also provided. Liquid samples were analyzed for glucose, xylose, arabinose, galactose, mannose, acetic acid, furfural, hydroxyl-methyl-furfural, and solubilized lignin. Solid samples were analyzed for glucan, xylan, arabinan, galactan, mannan, Klason lignin, acid-soluble lignin, and total ash. The enzymatic digestibilities of certain samples were determined.

Major Project Reports: See bibliography.

Summary Date: September 1995

Alternate Pretreatment Study—Dilute Acid and Organosolv

Directing Organization:

U.S. Department of Energy (DOE)
through the
National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Project Manager: J. Mielenz

Telephone: (303) 275-4489

Contractor:

Colorado State University
Fort Collins, CO 80523

Principal Investigators: H. Schroeder and J. Linden

Telephone: (970) 491-7768

Contract Numbers: XAW-3-11181-04;
XAW-4-14320-01

Contract Period: 1/93–12/95

Contract Funding (Source):

FY 1993: \$ 99,830 (DOE)
FY 1994: \$100,247 (DOE)

Objective:

Identify and develop pretreatment approaches that can improve ethanol production process performance and cost over the NREL base-case dilute sulfuric acid pretreatment process.

Approach/Background:

Pretreating lignocellulosic biomass is a key step in a successful biomass-to-ethanol conversion process. Until 1992, resources were focused on a dilute sulfuric acid pretreatment process, which has become part of the NREL base-case ethanol process. It is technically effective and economically promising, but has several areas for improvement, including reduced yields of furfural and hydroxyl-methyl furfural from, respectively, xylose, glucose, and reduced yields of other substances that may be toxic to cellulase enzymes and ethanol-fermenting yeasts; reduced levels of xylan remaining in pretreated solids; enhanced enzymatic digestibility of pretreated solids; and reduction or elimination of gypsum. This subcontract is one of several established to conduct research and development on other promising pretreatment processes. Phosphoric acid pretreatment and oxalic acid pretreatment with or without the presence of methanol were contracted to be studied.

Status/Accomplishments:

Pretreatment experiments of milled hybrid poplar, switchgrass, and corn stover/corn cobs mixture using dilute phosphoric acid and oxalic acid were conducted. Oxalic acid caused notable reactor corrosion and so was excluded from further study. Prehydrolyzates from organosolv runs using methanol showed high toxicity to yeast. Efforts are now directed toward dilute phosphoric acid and phosphoric acid-catalyzed organosolv pretreatments that use ethanol as the organic solvent.

Major Project Reports: See bibliography.

Summary Date: September 1995

Installation, Shakedown, and Operation of NREL Pretreatment Reactors

Directing Organization:

U.S. Department of Energy (DOE)
through the
National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Major Project Reports: None.

Summary Date: September 1995

Project Manager: J. Mielenz

Telephone: (303) 275-4489

Contractor:

Hazen Research, Inc.
4601 Indiana Street
Golden, CO 80401-3393

Principal Investigator: M. Berggren

Telephone: (303) 279-4501

Contract Number: YAC-4-14107-01

Contract Period: 2/95-2/96

Contract Funding (Source):

FY 1995: \$153,278 (DOE)

Objective:

Prepare standardized dilute-acid pretreated biomass solids and prehydrolyzates for NREL in-house research groups and subcontractors and conduct pretreatment research runs.

Approach/Background:

Several NREL research groups and subcontractors require pretreated biomass solids or liquors for research activities. Generating consistent pretreated solids and liquors for use is desirable. To ensure large quantities of consistent products are prepared, a 100-L ("paddle") and a 170-L ("Jaygo") reactor were designed and fabricated. These reactors, along with a laboratory-scale percolation reactor, are also used for pretreatment research. Hazen Research, Inc., was selected to operate these systems.

Status/Accomplishments:

The paddle and the percolation reactors have been installed and shaken down. Switchgrass, milled hybrid poplar, yellow poplar sawdust, mixed sawdust, and rice straw have been pretreated in the paddle reactor. Pretreatment products have been supplied to NREL and to subcontractors for evaluation. Preliminary pretreatment testing has begun using the percolation reactor. The Jaygo reactor is being shaken down and installed.

Optimization of Dilute-Acid Pretreatment of Selected Biomass Feedstocks

Directing Organization:

U.S. Department of Energy (DOE)
through the
National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Project Manager: J. Mielenz

Telephone: (303) 275-4489

Contractor:

Oregon State University
Corvallis, OR 97331-6602

Principal Investigators: M. Penner and
A. Hashimoto

Telephone: (503) 737-6513

Contract Number: XR-2-11186-1

Contract Period: 10/92-1/96

Contract Funding (Source):

FY 1993: \$120,081 (DOE)
FY 1994: \$154,504 (DOE)

Objective:

Establish optimal dilute sulfuric acid pretreatment conditions for selected biomass feedstocks that will result in maximum yields of ethanol equivalents (ethanol equivalents being proportional to the sum of the fermentable sugars produced in the course of pretreatment and glucose produced through enzymatic saccharification of the pretreated solids).

Approach/Background:

Previous research has shown that removing hemicellulose by dilute sulfuric acid prehydrolysis of lignocellulosic biomass renders cellulose accessible to cellulase enzymes. The extent of prehydrolysis depends on temperature, time, and acid concentration, and the reaction can be modeled as two parallel pseudo first-order reactions through which xylose is produced and (partially) degraded to nonfermentable compounds. The enzymatic digestibility of the remaining cellulose is, for a number of hardwoods, agricultural residues, and herbaceous crops, directly related to the extent of hemicellulose removal from the pretreated material. Potential ethanol yield depends on both the yield of xylose from hemicellulose and the enzymatic digestibility of the cellulose. Thus, a high yield of xylose and a high cellulose enzymatic digestibility are essential for economic

viability. Milled hybrid poplar, switchgrass, and a corn stover/corn cobs mixture were selected for this study.

Status/Accomplishments:

Pretreatment experimental runs that varied temperature (140°–180°C), acid concentration (0.6–1.2 wt %), and time (0.5–60 min) were conducted for milled hybrid poplar, switchgrass, and a corn stover/corn cobs mixture. A matrix of 50–60 data points was generated for each feedstock. Kinetic models were developed and apparent optimum conditions for maximum yields of xylose identified. Mass balances around the pretreatment operation were established. Pretreated solids produced under optimum conditions were tested in SSF studies for ethanol yields. The prehydrolyzates produced under optimum conditions are being tested for their fermentation toxicity.

Major Project Reports: See bibliography.

Summary Date: September 1995

Pretreatment of Lignocellulosic Materials by Pressure Cooking in Water

Directing Organization:

U.S. Department of Energy (DOE)
through the

National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Project Manager: J. Mielenz

Telephone: (303) 275-4489

Contractor:

Purdue University
West Lafayette, IN 47907

Principal Investigator: M.R. Ladisch

Telephone: (317) 494-7022

Contract Number: XAC-4-13511-01

Contract Period: 9/94-1/96

Contract Funding (Source):

FY 1994: \$149,217 (DOE)

Objective:

Characterize and develop a pH-controlled hot-water pretreatment process.

Approach/Background:

Pretreating lignocellulosic biomass is a key step in a successful biomass-to-ethanol conversion process. Numerous pretreatment techniques, including physical, chemical, and biological means, have been studied, and many are effective. None, however, has been commercialized. Currently, a number of pretreatment approaches, all of which (except this project), involve the use of one or more chemicals as catalyst, are supported for investigation by DOE through NREL. This project represents a different approach, in that high-temperature water treatment is to be used. A small amount of a chemical (a base) will be applied, only enough to control the pretreatment environment to near neutral conditions (pH 5 to 7). Thus, the chemical added is not to catalyze pretreatment reactions. Waste newsprint and yellow poplar sawdust are contracted to be studied.

Status/Accomplishments:

After initially testing several reactor configurations, a Parr Instrument stirred pressure reactor was found to be suitable for the project and has been procured. A semiautomatic pH control system is being installed.

Concomitantly, experimental runs of newsprint and sawdust are being conducted.

Major Project Reports: None.

Summary Date: September 1995

Alternate Pretreatment Study—Lime Pretreatment

Directing Organization:

U.S. Department of Energy (DOE)
through the
National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Project Manager: J. Mielenz

Telephone: (303) 275-4489

Contractor:

Texas A&M University
College Station, TX 77843-3124

Principal Investigator: M. Holtzapple

Telephone: (409) 845-9708

Contract Number: XAW-3-11181-03

Contract Period: 8/93–4/96

Contract Funding (Source):

FY 1993: \$118,667 (DOE)
FY 1994: \$ 99,902 (DOE)

Objective:

Identify and develop pretreatment approaches that could improve ethanol production performance over the observed NREL base-case dilute sulfuric acid pretreatment process.

Approach/Background:

Pretreating lignocellulosic biomass is a key step in a successful biomass-to-ethanol conversion process. Until 1993, resources were focused on a dilute sulfuric acid pretreatment process, which has become part of the NREL base-case ethanol process. Although technically effective and economically promising, this process has several areas for improvement, including reduced yields of furfural and hydroxymethyl furfural from xylose and glucose, respectively, and reduced yields of other substances that may be toxic to cellulase enzymes and ethanol-fermenting yeasts; reduced levels of xylan remaining in pretreated solids; enhanced digestibility of pretreated solids; and reducing or eliminating gypsum. This subcontract is one of several established to conduct research and development on other promising pretreatment processes. Lime pretreatment of milled switchgrass, whole-tree hybrid poplar, and corn stover/corn cobs mixture was contracted to be studied.

Status/Accomplishments:

During the first year we studied lime pretreatment of switchgrass. We conducted experiments that varied residence time, temperature, lime loading, water loading, and biomass particle size to determine the optimum or near optimum pretreatment conditions. The project is now in its second year, and investigates lime pretreatment of milled hybrid poplar and corn stover/corn cobs mixture.

Major Project Reports: See bibliography.

Summary Date: September 1995

Identify Inhibitory Components in Dilute-Acid Pretreated Lignocellulosic Materials

Directing Organization:

U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

Project Manager: J. Mielenz

Telephone: (303) 275-4489

Contractor:

Virginia Polytechnic Institute and State University
Blacksburg, VA 24061-0323

Principal Investigator: R. Helm

Telephone: (703) 231-4088

Contract Number: XAC-5-13363-01

Contract Period: 11/94-10/96

Contract Funding (Source):
FY 1991: \$180,000 (DOE)

Objective:

To conduct detailed compositional analyses of solid and hydrolyzate fractions of a selected dilute-acid pretreated biomass feedstock and identify the inhibitory compounds that adversely affect fermentation performance. This information will be used to develop strategies to alleviate inhibition of fermentation performance.

Approach/Background:

Relatively poor conversion of neutralized dilute-acid pretreated hardwood feedstocks is attributed to the presence of inhibitory compounds that deleteriously affect the microorganisms used to ferment biomass sugars to ethanol. Suspected inhibitors include compounds present in raw biomass and those formed or released during pretreatment. To develop an economical biomass-to-ethanol process, the composition of dilute-acid pretreated biomass feedstocks must be characterized, and inhibitory compounds, their inhibition mechanisms, and their probable fates in an integrated biomass-to-ethanol process identified.

Status/Accomplishments:

High-pressure liquid chromatography, gas chromatography, and gas chromatography/mass spectrometry are being used to identify and quantify suspected inhibitory compounds present in dilute-acid pretreated mixed hardwood sawdust solids and hydrolyzate liquor. The first year's work focused on analyzing the hydrolyzate liquor. In addition to acetic acid,

hydroxyl-methyl-furfural, and furfural, suspected inhibitors include gallic acid, vanillin, protocatechuic acid, sinapic acid, coniferyl alcohol, and syringaldehyde. Hydrolyzate liquor fractions and individual putative inhibitory compounds are also being tested for toxicity to growth and xylose fermentation using NREL's recombinant *Zymomonas*. The near-term goal is to develop a list of putative inhibitory compounds ranked in order of their concentration in pretreatment liquor and their relative toxicity. Second-year efforts will focus on identifying additional inhibitory compounds and characterizing the toxicity of previously identified inhibitory components to growth and fermentation using *Saccharomyces cerevisiae*.

Major Project Reports: None.

Summary Date: September 1995

Alternate Pretreatment Study—Alkaline Peroxide Extrusion

Directing Organization:

U.S. Department of Energy (DOE)
through the
National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Project Manager: J. Mielenz

Telephone: (303) 275-4489

Contractor:

Xylan, Inc.
510 E. South Street
Mankato, KS 66956

Principal Investigator: G. Tyson

Telephone: (913) 378-3890

Contract Number: XAW-3-11181-05;
HAW-4-14167-01

Contract Period: 1/93–6/95

Contract Funding (Source):

FY 1993: \$98,673 (DOE)
FY 1994: \$89,677 (DOE)

Objective:

Identify and develop pretreatment approaches that could improve ethanol production performance over the observed NREL base-case dilute sulfuric acid pretreatment process.

Approach/Background:

Pretreating lignocellulosic biomass is a key step in a successful biomass-to-ethanol conversion process. Until 1992, resources were focused on a dilute sulfuric acid pretreatment process, which has become part of the NREL base-case ethanol process. It is technically effective and economically promising, but has several areas for improvement, including reduced yields of furfural and hydroxyl-methyl furfural from, respectively, xylose and glucose, and reduced yields of other substances that may be toxic to cellulase enzymes and ethanol-fermenting yeasts; reduced levels of xylan remaining in pretreated solids; enhanced enzymatic digestibility of pretreated solids; and reduction or elimination of gypsum. This subcontract is one of several established to conduct research and development on other promising pretreatment processes. Alkaline peroxide extrusion pretreatment of whole-tree hybrid poplar chips, coarsely milled switchgrass, and a coarsely milled corn stover/corn cobs mixture were contracted to be investigated.

Status/Accomplishments:

Using the optimal pretreatment conditions known to the contractor, the alkaline peroxide extrusion pretreated hybrid poplar, upon simultaneous saccharification and fermentation produced an ethanol yield of 32% of theoretical conversion, based on cellulose available in the pretreated solids. With switchgrass and a corn stover/corn cobs mixture, the ethanol yields were, respectively, 33% and 48%.

Major Project Reports: See bibliography.

Summary Date: September 1995

Cofermentation Biocatalyst Development

Directing Organization:

U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

Project Manager: J. Mielenz

Telephone: (303) 275-4489

Contractor:

National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, CO 80401-3393

Principal Investigators: S. Picataggio and
M. Zhang

Telephone: (303) 384-6107

Contract Number: DE-AC02-83CH10093

Contract Period: 11/94–10/95

Contract Funding (Source):
FY 1995: \$747,000 (DOE)

Objective:

Develop novel microorganisms that can rapidly and efficiently coferment the hexose and pentose sugars in lignocellulosic hydrolysates to ethanol.

Approach/Background:

Sensitivity analysis of the base case biomass-to-ethanol process indicates substantial savings in capital and operating costs associated with advanced process designs in which hexose and pentose sugars are simultaneously cofermented to ethanol. There are microorganisms that can efficiently ferment the glucose component in cellulose to ethanol; however, because there is no suitable biocatalyst, converting the pentose sugars such as xylose and arabinose in the hemicellulose fraction is more difficult.

Simultaneously cofermenting these sugars is further hindered by the repressive effect of the glucose liberated during enzymatic hydrolysis of cellulose. A comprehensive survey identified the bacteria *Zymomonas mobilis* and *Lactobacillus* as promising microorganisms for further development as cofermentation biocatalysts.

Status/Accomplishments:

A new strain of *Z. mobilis* has been metabolically engineered to simultaneously coferment the glucose and xylose—prominent in many lignocellulosic feedstocks—to ethanol. Engineered strains that

demonstrate the best cofermentation performance in sawdust hydrolysate were identified for scaleup to the PDU. The substrate utilization range of this new biocatalyst has been further expanded for fermenting the arabinose commonly found in agricultural residues such as corn fiber and in herbaceous energy crops such as switchgrass. In a first step to develop a thermotolerant ethanologenic cofermentation biocatalyst, a strain of *Lactobacillus* with superior resistance to dilute-acid hydrolysates at elevated temperatures and the ability to ferment many other sugars commonly found in lignocellulosic feedstocks, including glucose, cellobiose, mannose, and arabinose, has been metabolically engineered to produce lactate from xylose at near-theoretical yield.

Major Project Reports: See bibliography.

Summary Date: September 1995

Cofermentation Process Development

Directing Organization:

U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

Project Manager: J. Mielenz

Telephone: (303) 275-4489

Contractor:

National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, CO 80401-3393

Principal Investigators: S. Picataggio and
J. McMillan

Telephone: (303) 384-6107

Contract Number: DE-AC02-83CH10093

Contract Period: 11/94-10/95

Contract Funding (Source):

FY 1995: \$484,000 (DOE)

Objective:

Develop and evaluate advanced process designs based on the use of xylose-fermenting strains of *Zymomonas mobilis* to rapidly and efficiently coferment the glucose and xylose in lignocellulosic feedstocks to ethanol.

Approach/Background:

Sensitivity analysis of the base-case biomass-to-ethanol process indicates substantial savings in capital and operating costs associated with advanced process designs in which the hexose and pentose sugars in lignocellulosic feedstocks are simultaneously cofermented to ethanol. Several microorganisms can efficiently ferment the glucose component in cellulose to ethanol, but converting pentose sugars, such as xylose, in the hemicellulose fraction is more difficult. Recently, NREL scientists metabolically engineered a new strain of the bacterium *Z. mobilis* that can simultaneously coferment the glucose and xylose—prominent in many lignocellulosic feedstocks—to ethanol.

Status/Accomplishments:

Research is being conducted to develop advanced processes to coferment the predominant hexose and pentose sugars in lignocellulosic feedstocks to ethanol. Using metabolically engineered strains of *Z. mobilis* developed at NREL, cofermentation processes based on simultaneous saccharification and cofermentation (SSCF), separate hydrolysis and cofermentation

(SHCF), and hybrid SSCF/SHCF configurations are being evaluated using statistically designed experiments and response surface analysis. Preliminary cofermentation processing conditions that maximize the ethanol yield and concentration from dilute-acid pretreated hardwood sawdust and minimize the fermentation time will be established for scaleup to the process development unit.

Major Project Reports: See bibliography.

Summary Date: September 1995

Demonstrate Direct Microbial Conversion (DMC) Process

Directing Organization:

U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

Project Manager: J. Mielenz

Telephone: (303) 275-4489

Contractor:

Thayer School of Engineering
Dartmouth College
Hanover, NH 03755-8000

Principal Investigator: L. Lynd

Telephone: (604) 646-2231

Contract Number: XAC-5-15162-01

Contract Period: 3/95-2/96

Contract Funding (Source):

FY 1995: \$110,000 (DOE)

Objective:

Demonstrate an integrated direct microbial conversion (DMC) process on a relevant feedstock using a mixed culture of *Clostridium thermosaccharolyticum* and *Clostridium thermocellum*.

Approach/Background:

The DMC process is considered a promising advanced technology for biomass conversion because it consolidates all bioprocessing steps into a single unit operation, with significant savings in capital and operating costs; and it uses high temperatures, thus reducing cooling requirements, product recovery costs, and the risk of contamination. The DMC process utilizes a mixed culture of two thermophilic bacteria, *C. thermocellum* and *C. thermosaccharolyticum*, to convert cellulosic biomass to ethanol. The DMC process is not yet economically attractive, however, because these bacteria conduct mixed-acid fermentations and exhibit low ethanol selectivity. Also, biomass sugar conversion has yet to be demonstrated at practical substrate concentrations using cost-effective nutrients and actual pretreatment hydrolyzates.

Status/Accomplishments:

Research is being conducted to develop a process medium based on the use of commercial components (e.g., corn steep liquor, molasses, yeast extract) that supports xylose fermentation by *C. thermosaccharolyticum* at moderate to high xylose feed concentrations and demonstrates a reproducible continuous DMC

process for wastepaper sludge supplemented with D-xylose using a mixed culture of *C. thermocellum* and *C. thermosaccharolyticum*. A steady-state continuous culture that completely utilizes a 50 g/L xylose feed has been reproducibly demonstrated with *C. thermosaccharolyticum*. Previous efforts to completely utilize 50 g/L xylose were unsuccessful, so this represents a significant achievement. Complete utilization of a 75 g/L xylose feed is now being pursued. Research on the second objective is being directed at developing a feed delivery system that will enable concentrated wastepaper feedstock slurry to be delivered to a continuous reactor.

Major Project Reports: See bibliography.

Summary Date: September 1995

Continuous Bioreactors for Conversion of Paper Sludge to Ethanol

Directing Organization:
U.S. Department of Energy (DOE)
through the
National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Major Project Reports: None.
Summary Date: September 1995

Project Manager: J. Mielenz
Telephone: (303) 275-4489

Contractor:
Thayer School of Engineering
Dartmouth College
8000 Cummings Hall
Hanover, NH 03755-8000

Principal Investigator: L. Lynd
Telephone: (604) 646-2231

Contract Number: to be determined
Contract Period: 11/95-10/96

Contract Funding (Source):
FY 1996: \$100,000 (DOE)

Objective:

Evaluate the technical and economic feasibility of producing ethanol from paper sludge using a continuous simultaneous saccharification and fermentation process and on-site cellulase production.

Approach/Background:

Paper sludge, a waste material from the paper industry, is a particularly attractive ethanol feedstock because of negative feedstock cost, much-simplified technology compared to a grass-roots plant, and the availability of an extensive infrastructure that can provide utilities at incremental cost. Continuous bioreactors generally, and the recently patented continuous solids-retaining bioreactor in particular, may offer an effective response to the challenges associated with processing sludge into ethanol.

Continuous cellulase production will be investigated because it should result in higher productivity relative to batch or fed-batch operations.

Status/Accomplishments:

This project is expected to commence in November 1995.

Pentose Sugar Transport in *Zymomonas*

Directing Organization:

U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

the foundation for attempts to improve the efficiency of pentose transport in recombinant *Z. mobilis*, which will be the focus of the second year of research.

Project Manager: J. Mielenz

Telephone: (303) 275-4489

Major Project Reports: None.

Summary Date: September 1995

Contractor:

Ohio State University
Columbus, OH 43210

Principal Investigator: T. Conway

Telephone: (614) 688-3518

Contract Number: XCF-5-14328-01

Contract Period: 1/95–1/97

Contract Funding (Source):

FY 1994: \$125,000 (DOE)

Objective:

Evaluate the transport of pentose sugars in wild-type and xylose-fermenting strains of *Zymomonas mobilis*.

Approach/Background:

Sensitivity analysis of the base-case biomass-to-ethanol process indicates substantial savings in capital and operating cost associated with advanced process designs in which the hexose and pentose sugars in lignocellulosic feedstocks are simultaneously cofermented to ethanol. Recently, NREL scientists metabolically engineered a new strain of the bacterium *Z. mobilis* that can simultaneously coferment the glucose and xylose—prominent in many lignocellulosic feedstocks—to ethanol. Information on pentose sugar transport in this strain is essential to further develop superior biocatalysts and processes to simultaneously coferment these sugars to ethanol.

Status/Accomplishments:

Research is being conducted to determine the kinetics of xylose and arabinose transport in wild-type and metabolically engineered strains of *Z. mobilis* in the presence and absence of glucose, and to evaluate the substrate specificity of individual *Z. mobilis* transport systems. This research will identify the primary systems responsible for pentose sugar transport and determine the conditions under which these transporters are most active. Research may also suggest strategies by which pentose transport systems can be altered to maximize the rate of pentose transport. Research conducted during the first year will provide

Evaluate Inoculum Preparation Techniques for Cellulose Conversion to Ethanol

Directing Organization:

U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

Project Manager: J. Mielenz

Telephone: (303) 275-4489

Contractor:

Southern Research Institute
P.O. Box 55305
Birmingham, AL 35255-5305

Principal Investigator: D. Rivers

Telephone: (205) 581-2000

Contract Number: YAP-3-11206-01

Contract Period: 8/93-10/95

Contract Funding (Source):

FY 1991: \$141,000 (DOE)

Objective:

Determine the conditions that maximize the rate and extent of yeast cell mass production during seed preparation and the ethanol production rate during simultaneous saccharification and fermentation (SSF), while minimizing seed fermentation energy needs and the lag phase in SSF.

Approach/Background:

Yeast seed cultivation techniques, including those used at industrial scales, will be identified and evaluated to determine their effect on SSF performance. The most promising techniques will be selected for further optimization. The effects of nutrient composition, aeration, and agitation during seed cultivation on SSF ethanol productivity will be quantified. Strategies will be developed to minimize seed cultivation requirements while maintaining optimal cell growth and product formation. Aerobic and anaerobic batch, fed-batch, and continuous seed fermentations will be considered.

Status/Accomplishments:

Parameters for yeast seed production and use in SSF were investigated using *Saccharomyces cerevisiae* D₅A. Results indicate that 1% (w/v) glucose is adequate to produce the quantity of yeast seed required for SSF, and that a 2.5% (v/v) seed inoculum is sufficient to produce the required quantity of yeast cells in an 8-hour residence time. However, using corn

steep liquor (CSL) as the sole nutrient source for both seed production and SSF, 7-day SSF yields on either pure Avicel cellulose or pretreated poplar were less than 10% of theoretical. In contrast to the subcontractors findings, research conducted at NREL has shown CSL to be an adequate sole nutrient source for seed production and high-yield SSF.

Major Project Reports: None.

Summary Date: September 1995

Cofermentation Medium for *Zymomonas*

Directing Organization:

U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

Project Manager: J. Mielenz

Telephone: (303) 275-4489

Contractor:

University of Toronto
Toronto, Ontario, Canada M5S 1A8

Principal Investigator: H. Lawford

Telephone: (416) 978-7096

Contract Number: AAP-4-11195-03 (Phase II)

Contract Period: 3/95-3/96

Contract Funding (Source):

FY 1994: \$100,000 (DOE)

Objective:

Define process conditions that incorporate the use of commercial nutrient sources that maximize cell yield in seed preparation and ethanol yield and productivity in cofermentation of glucose and xylose by a xylose-fermenting strain of *Zymomonas mobilis*.

Approach/Background:

Sensitivity analysis of the base-case biomass-to-ethanol process indicates substantial savings in capital and operating cost associated with advanced process designs in which the hexose and pentose sugars in lignocellulosic feedstocks are simultaneously cofermented to ethanol. Recently, NREL scientists metabolically engineered a new strain of the bacterium *Z. mobilis* that can simultaneously coferment glucose and xylose—prominent in many lignocellulosic feedstocks—to ethanol. Information on the commercial nutrient sources and process conditions that maximize cell yield, ethanol yield, and productivity are essential to the development of a cost-effective cofermentation process.

Status/Accomplishments:

Research is being conducted to determine the nutrient requirements for growing and cofermenting glucose and xylose by a selected xylose-fermenting strain of *Z. mobilis*. Subsequent research will identify inexpensive commercial nutrient sources and process conditions that maximize cell yield in seed preparation and ethanol yield and productivity in a batch simultaneous saccharification and cofermentation (SSCF) process

for converting the glucose and xylose present in pretreated hardwood sawdust.

Major Project Reports: None.

Summary Date: September 1995

Genetic Engineering of Xylose-Fermenting Yeasts

Directing Organization:

U.S. Department of Energy (DOE)
1000 Independence Avenue, SW
Washington, DC 20585

Project Manager: J. Mielenz

Telephone: (303) 275-4489

Contractor:

University of Wisconsin
Madison, WI 53706

Principal Investigator: T. Jeffries

Telephone: (608) 231-9453

Contract Number: XAU-4-11193-02

Contract Period: 11/93–11/95

Contract Funding (Source):

FY 1995: \$95,000 (DOE)

Objective:

To develop an improved ethanologenic yeast that can efficiently ferment xylose when genetic engineering techniques are applied.

Approach/Background:

Efficiently converting the xylose in the hemicellulose fraction to ethanol remains one of the economic bottlenecks in the current conversion scheme. *Candida shehatae* and *Pichia stipitis* can ferment xylose, but at rates and yields less than required for commercial production. This work is directed toward increasing the ethanol yield and productivity of these yeasts by overexpressing and deleting selected genes, evaluating their xylose fermentation performance, and implementing strategies that maximize anaerobic fermentation yield.

Status/Accomplishments:

Using a genetic transformation system based on complementing a uracil-requiring mutant, the *P. stipitis* xylose reductase (XYL1) gene, the *Zymomonas mobilis* alcohol dehydrogenase (ADH2) gene, and the *Saccharomyces cerevisiae* pyruvate decarboxylase (PDC1) and alcohol dehydrogenase (ADH1) genes have been introduced into *P. stipitis*. *P. stipitis* strains that carry XYL1, PDC, or PDC and ADH genes demonstrated as much as a 22% increase in ethanol volumetric productivity and a 32% increase in ethanol yield compared to the control strain. Furthermore, genes have been successfully replaced in the *P. stipitis* genome for the first time. This advance establishes the

techniques necessary for targeted inactivation of the PDH E¹α (pyruvate dehydrogenase E¹α subunit) and CYC1 (cytochrome c) genes that are believed to adversely affect the ethanol yield and anaerobic growth. Subsequent research will be directed toward simultaneously expressing and inactivating selected genes to improve ethanol productivity and maximize anaerobic fermentation yield.

Major Project Reports: See bibliography.

Summary Date: September 1995

Cellulase Development

Directing Organization:

U.S. Department of Energy (DOE)
1000 Independence Avenue, SW
Washington, DC 20585

Project Manager: J. Mielenz

Telephone: (303) 275-4489

Contractor:

National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Principal Investigator: S. Thomas

Telephone: (303) 384-6187

Contract Number: DE-AC04-83CH10093

Contract Period: 10/92-10/95

Contract Funding (Source):

FY 1993: \$1,317,000 (DOE)
FY 1994: \$1,555,000 (DOE)
FY 1995: \$ 840,000 (DOE)

Objectives:

- Purify, characterize, and compare cellulases from a variety of organisms to determine which have the highest specific activity, the best match to anticipated process hydrolysis and fermentation conditions, and the ability to act synergistically to enhance the rate of cellulose hydrolysis
- Develop cost-effective, highly productive, industrially acceptable, genetically engineered organisms for the production of well balanced, multi-enzyme cellulase systems to efficiently and completely hydrolyze cellulose.

Approach/Background:

Identifying extremely active cellulase enzymes to depolymerize cellulose is an important first step in developing an economical enzyme production process. Cloning selected cellulase genes from microorganisms that produce high specific-activity cellulases at very high levels in appropriate hosts will permit production of the most effective cellulase systems. The ability to select and overproduce these cellulases will significantly lower the cost of producing cellulases, significantly increase the rate of lignocelulosic biomass hydrolysis, or both, thereby reducing the cost of producing ethanol.

Status/Accomplishments:

Purified enzymes supplied by subcontractors associated with this activity, and our own work, have permitted extensive comparative biochemical studies to be carried out, resulting in the ability to rationalize which genetic constructions should be built. Several endo- and exoglucanase, and β -glucosidase genes cloned at NREL and elsewhere function in heterologous host bacteria, such as *Escherichia coli*, *Streptomyces lividans*, and *Bacillus subtilis*. The gene for the highly active, thermotolerant *Acidothermus cellulolyticus* E1 endoglucanase has been completely sequenced, permitting the construction of several expression vectors for this endoglucanase in *E. coli*, *S. lividans*, and *Pichia pastoris*. The *P. pastoris* system can produce more than 1 gram of the E1 endoglucanase per liter of culture.

Major Project Reports: See bibliography.

Summary Date: September 1995

Fungal Cellulases

Directing Organization:

U.S. Department of Energy (DOE)
1000 Independence Avenue, SW
Washington, DC 20585

Project Manager: J. Mielenz

Telephone: (303) 275-4489

Contractor:

National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Principal Investigator: M. Himmel

Telephone: (303) 384-6299

Contract Number: DE-AC04-83CH10093

Contract Period: 11/94-10/95

Contract Funding (Source):
FY 1995: \$210,000 (DOE)

Objectives:

- Assess the relative efficacy of commercially available cellulase preparations on programmatic feedstock materials, including pretreated hardwood sawdusts and agricultural residues
- Establish relationships with cellulase manufacturers and make them aware of the need for developing inexpensive and effective sources of cellulase for converting biomass to ethanol
- Furnish guidance to cellulase manufacturers willing to devote resources to developing effective and cost-efficient cellulase preparations customized for use in biomass conversion processes.

Approach/Background:

The technology for producing an effective and economical cellulase for use in first-generation biomass conversion technology will approximate that used by commercial enzyme manufacturers. The filamentous fungus, *Trichoderma reesei*, is the production organism for most cellulase manufacturers, although cellulases from other fungi are also available. The many cellulase preparations available commercially differ in terms of the organism, the fermentation conditions, and the downstream processing steps used to concentrate, stabilize, and package the preparation. Whether any of these variables significantly affect the quality of these preparations for use in biomass conversion processes is not known. However, the cellulose component of feedstock materials derived

from different sources is not equally digestible after equivalent pretreatments.

Status/Accomplishments:

An apparatus has been designed and tested with cellulosic substrates that permits nearly complete saccharification while eliminating reaction products from the reactor to minimize the effects of product feedback inhibition, thus maximizing reaction kinetics. This apparatus has been used with various combinations of purified endo- and exoglucanases and shows clear differences in the relative performance of different enzyme cocktails.

High-level contacts have been made with each major cellulase manufacturer in North America. The need for large quantities of effective and inexpensive cellulase preparations in the near term has been made clear to each of them. We are continuing to develop these relationships.

Major Project Reports: None.

Summary Date: September 1995

Cellulase Structure

Directing Organization:

U.S. Department of Energy (DOE)
through the
National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Project Manager: J. Mielenz

Telephone: (303) 275-4489

Contractor:

Section of Biochemistry,
Molecular and Cell Biology
Cornell University
Ithaca, NY 14853

Principal Investigator: P.A. Karplus

Telephone: (607) 255-5701

Contract Number: XAH-5-15113-01

Contract Period: 3/95-3/96

Contract Funding (Source):

FY 1995: \$ 75,000 (DOE)

Objective:

Crystallize a pure preparation of the *Acidothermus cellulolyticus* E1 endoglucanase catalytic domain and elucidate its three-dimensional structure at the highest possible resolution using x-ray crystallography techniques. Help NREL researchers plan approaches to genetically improve this endoglucanase.

Approach/Background:

Genetically improving an enzymatic activity can best be approached in a directed fashion if a reliable three-dimensional crystal structure is known for the target protein. X-ray crystallography provides the only known approach to the solution of this problem for a protein the size of the E1 catalytic domain.

Status/Accomplishments:

Crystals of the E1 catalytic domain have been produced and subjected to x-ray bombardment. The data collected have been refined into an excellent model for the 358 amino acid protein with a resolution of approximately 2.4 Å.

Major Project Reports: None.

Summary Date: September 1995

Cellulases from *Thermomonospora fusca*

Directing Organization:

U.S. Department of Energy (DOE)
through the
National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Project Manager: J. Mielenz

Telephone: (303) 275-4489

Contractor:

Section of Biochemistry,
Molecular and Cell Biology
Cornell University
Ithaca, NY 14853

Principal Investigator: D.B. Wilson

Telephone: (607) 255-5706

Contract Number: XAC-3-13260-01

Contract Period: 4/93-6/96

Contract Funding (Source):

FY 1991: \$ 94,878 (DOE)

FY 1991: \$124,852 (DOE)

FY 1994: \$ 90,439 (DOE)

Objectives:

- Purify and characterize large quantities of active endo- and exoglucanases from the cellulolytic bacterium, *Thermomonospora fusca*
- Isolate and characterize cellulase genes from *T. fusca*
- Design and construct recombinant microbial overexpression systems for selected cellulases
- Genetically improve the biochemical characteristics of the E₂ endoglucanase via protein engineering.

Approach/Background:

T. fusca is a thermotolerant bacterium that produces endo- β -1,4-glucanases with very high specific activities. It is also one of the few known bacterial systems that expresses active, highly synergistic exo- β -1,4-glucanases. Proteins are purified by classical chromatography techniques from native and recombinant cultures of microorganisms.

Status/Accomplishments:

Milligram quantities of several endoglucanases and an exoglucanase have been purified from native and recombinant sources by standard chromatographic

techniques. A 1.0- \AA resolution x-ray crystal structure has been solved for the *T. fusca* E₂ endoglucanase. The x-ray model is being used to guide experiments designed to alter and improve the biochemical characteristics of the E₂ protein. Mutants in 15 residues have been constructed and are being characterized. *T. fusca* genes for six endo- and exocellulases have been cloned, sequenced, and expressed in *Streptomyces lividans*.

Major Project Reports: See bibliography.

Summary Date: September 1995

Cellulases from *Clostridium thermocellum*

Directing Organization:

U.S. Department of Energy (DOE)
through the
National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Project Manager: J. Mielenz

Telephone: (303) 275-4489

Contractor:

Department of Chemical Engineering
University of Rochester
Gavett Hall, Room 206
Rochester, NY 14627

Principal Investigator: J.H.D. Wu

Telephone: (716) 275-8499

Contract Number: XAC-3-13419-01

Contract Period: 8/93-12/95

Contract Funding (Source):

FY 1993: \$106,080 (DOE)
FY 1994: \$ 99,215 (DOE)

Objectives:

- Purify and characterize large quantities of active endo- and exoglucanases from the cellulolytic anaerobic bacterium, *Clostridium thermocellum*
- Isolate and characterize cellulase genes from *C. thermocellum*
- Develop genetically engineered expression systems for *C. thermocellum* cellulases.

Approach/Background:

C. thermocellum produces a cellulase system that consists of more than a dozen polypeptides, which function together as a tightly associated particulate system (cellulosome) at the bacterial cell surface. This strategy for cellulose degradation is common to many anaerobic cellulolytic organisms and provides an important alternative to the freely soluble cellulases being investigated by other subcontractors.

Status/Accomplishments:

A genomic library of *C. thermocellum* DNA has been constructed in *Escherichia coli*. Genes for the anchorage and scaffolding protein, CelL, and a key catalytic subunit, CelS, have been cloned and sequenced. Recombinant CelS has been characterized, and represents a novel class of exoglucanase. An important endoglucanase gene, celD, has been cloned and expressed in a recombinant system to purify large quantities of the CelD protein for biochemical characterization at NREL. An expression system has also been developed for the celS gene.

Major Project Reports: See bibliography.

Summary Date: September 1995

Cellulases from *Microbispora bispora*

Directing Organization:

U.S. Department of Energy (DOE)
through the
National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Project Manager: J. Mielenz

Telephone: (303) 275-4489

Contractor:

Department of Microbiology
Rutgers University
Lipman Hall, Room 333A
New Brunswick, NJ 08903

Principal Investigator: D. Eveleigh

Telephone: (908) 932-9829

Contract Number: XD-2-11201-01

Contract Period: 1/92-12/95

Contract Funding (Source):

FY 1991: \$89,979 (DOE)

FY 1991: \$62,880 (DOE)

FY 1994: \$74,557 (DOE)

Objectives:

- Purify and characterize large quantities of active endo- β -1,4-glucanases, exo- β -1, 4-glucanases, and β -D-glucosidases from the cellulolytic, thermotolerant bacterium, *Microbispora bispora*
- Isolate and thoroughly characterize cellulase and β -glucosidase genes from *M. bispora*
- Design and construct recombinant expression systems for *M. bispora* cellulases and β -glucosidases.

Approach/Background:

M. bispora is a thermotolerant, composting bacterium that produces high specific-activity endo- β -1, 4-glucanases, and a cellobiase activity that is extremely resistant to product feedback inhibition by glucose. Proteins are purified by classical chromatography techniques from native and recombinant cultures of microorganisms.

Status/Accomplishments:

Milligram quantities of endoglucanase A have been purified from a recombinant source by standard chromatographic techniques and supplied to NREL

for testing. The *M. bispora* genes for one endoglucanase and two β -glucosidases have been cloned and sequenced.

Major Project Reports: See bibliography.

Summary Date: September 1995

Cellulases from *Thermotoga neapolitana*

Directing Organization:

U.S. Department of Energy (DOE)
through the
National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Project Manager: J. Mielenz

Telephone: (303) 275-4489

Contractor:

Department of Microbiology
Rutgers University
Lipman Hall, Room 333A
New Brunswick, NJ 08903

Principal Investigator: D. Eveleigh

Telephone: (908) 932-9829

Contract Number: XC-2-11179-01

Contract Period: 08/92-12/95

Contract Funding (Source):

FY 1991: \$30,000 (DOE)
FY 1991: \$67,498 (DOE)
FY 1994: \$76,315 (DOE)

Objectives:

- Purify and characterize large quantities of active endoglucanases and 1,4- β -D-glucosidases from the bacterium *Thermotoga neapolitana*
- Isolate and characterize endo- β -1,4-glucanase and β -D-glucosidase genes from *T. neapolitana*
- Design and build genetically engineered over-expression systems for *T. neapolitana* cellulase genes.

Approach/Background:

T. neapolitana is a hyperthermophilic eubacterium isolated from a deep-sea ocean vent that produces highly thermotolerant, very high specific-activity endo- β -1,4-glucanases. Proteins are purified by classical chromatography techniques.

Status/Accomplishments:

Milligram quantities of *T. neapolitana* endoglucanase B have been purified by standard chromatographic techniques and supplied to NREL for testing.

Major Project Reports: See bibliography.

Summary Date: September 1995

Compositional Analysis of Biomass Samples

Directing Organization:

U.S. Department of Energy (DOE)
through the
National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Project Manager: J. Mielenz

Telephone: (303) 275-4489

Contractor:

Hauser Chemical Research, Inc.
5555 Airport Boulevard
Boulder, CO 80301

Principal Investigator: D. Timmons

Telephone: (303) 443-4662

Contract Numbers: RAC-4-14108; RCF-4-14270

Contract Period: 3/94-4/96

Contract Funding (Source):

FY 1994: \$228,880 (DOE)
FY 1995: \$185,940 (DOE)

Objective:

Use an outside analytical testing laboratory to provide precise and accurate compositional analysis of routine lignocellulosic samples of interest to the ethanol project. This analytical information will supplement the more complex and nonroutine analyses conducted by the Chemical Analysis and Testing (CAT) Task. The data will be used by ethanol project research groups to meet specific technical objectives defined in the annual operating plan.

Approach/Background:

Routine feedstock, pretreated biomass, and the solid fraction of fermentation residues are to be analyzed for total solids, acid-insoluble and acid-soluble lignin, cellulose (as glucose), hemicellulosic sugars, starch, and ash. Pretreatment liquors and the liquid fraction of fermentation samples are to be analyzed for total and total dissolved solids, cellobiose, monomeric and total sugars, organic acids, glycerol, hydroxyl-methyl furfural, and furfural. During the course of these analyses, established CAT Task Laboratory Analytical Procedures and the QC protocols described in the ethanol project quality assurance program must be followed. The results of each group of analyses are reported to the CAT Task for evaluation and data reduction.

Status/Accomplishments:

Two hundred eleven samples were analyzed during the first year. Assay reproducibility and analysis turnaround time consistently met or exceeded expectations. The overall sample load for the second year is expected to be significantly higher, but improvements made to methods and reporting requirements have streamlined the process and reduced the overall analysis cost per sample.

Major Project Reports: See bibliography.

Summary Date: September 1995

Develop and Maintain Project QA/QC Program

Directing Organization:

U.S. Department of Energy (DOE)
1000 Independence Avenue, SW
Washington, DC 20585

Project Manager: J. Mielenz

Telephone: (303) 275-4489

Contractor:

National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Principal Investigator: C. Ehrman

Telephone: (303) 275-4444

Contract Number: DE-AC04-83CH10093

Contract Period: 10/93-10/95

Contract Funding (Source):

FY 1994: \$170,000 (DOE)
FY 1995: \$161,000 (DOE)

Objective:

Develop, implement, and monitor a project-wide QA/QC program that will result in the highest possible level of work quality, reproducibility, and utility.

Approach/Background:

The goal of a strong research program to produce high-quality data via well-designed experimental protocols and analytical measurements is usually reached when the experimental work is conducted within the confines of good QC practices. The ethanol project quality assurance program was developed and implemented with this goal in mind. The program is based on a detailed quality assurance plan (QAP) designed to be the foundation for the quality assurance program.

Status/Accomplishments:

A major step in developing the quality assurance program was designing and writing the QAP, which guides research and analytical activities by describing policies, goals, areas of responsibility, specific QC activities, standard analytical procedures, a system of quality experimental planning, and the means to document these activities. The concepts, protocols, and tools contained in the QAP are purposely flexible so they can be tailored to meet the needs of each experimental group.

A multistep implementation strategy for the quality assurance program was initiated to assimilate the plan

into daily activities of the project, both in-house and subcontract. Established analytical procedures have been updated to include rigorous QC criteria, and, as new methods have been developed, they have undergone a stringent validation and documentation process. New conformance evaluation and method verification standards have been identified and validated as tools for assessing the quality of generated analytical results. Current efforts are being directed toward helping individual research groups with issues or problems they may have encountered when implementing their procedures.

Major Project Reports: See bibliography.

Summary Date: September 1995

Analyze Complex Samples and Develop Methods

Directing Organization:

U.S. Department of Energy (DOE)
1000 Independence Avenue, SW
Washington, DC 20585

Project Manager: J. Mielenz

Telephone: (303) 275-4489

Contractor:

National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Principal Investigator: C. Ehrman

Telephone: (303) 275-4444

Contract Number: DE-AC04-83CH10093

Contract Period: 10/92-10/95

Contract Funding (Source):

FY 1993: \$300,000 (DOE)
FY 1994: \$464,000 (DOE)
FY 1995: \$502,000 (DOE)

Objective:

Analyze complex samples and develop and validate methods in response to new analytical needs to support ethanol project activities.

Approach/Background:

Ethanol project researchers require reliable analytical data to evaluate feedstocks, process intermediates, and end products from biomass conversion and assess the effectiveness of each stage of the process. By analyzing complex samples to develop standard analytical methods and produce precise and accurate data, we provide a certified analytical service to meet project research goals. High-quality analytical data are acquired via analytical measurements and protocols that meet the QC principles established in the quality assurance plan. Submitted samples are analyzed by a highly trained team that uses Laboratory Analytical Procedures (LAPs) and methods developed and validated specifically in response to a new analytical need. This information is used to meet the technical objectives of the research groups within the project.

Status/Accomplishments:

During FY 1994, we processed 134 chemical analysis work orders, which represented more than 1600 samples from project researchers, subcontractors, and CRADA partners. To date in FY 1995, more than 100

work orders and almost 1400 samples have been processed. The work requests involved a wide range of analyses that used LAPs and newly developed and validated methods. Because of stringent QA/QC criteria, the analytical results are considered to be of the highest quality.

Changing project needs and new problems often require that we develop innovative analytical approaches, procure new instruments (and concurrently develop instrumental procedures), and enhance procedures. Such efforts have enabled us to validate a series of new or enhanced methods for analyzing samples. We developed methods that use high-performance anion exchange chromatography with pulsed amperometric detection to analyze carbohydrates, sugar reversion products, and degradation products. An instrumental technique was developed to determine carbon, hydrogen, and nitrogen in biomass samples, which can be directly applied to the determination of the protein content of feedstock and process samples. An advanced method for analyzing ethanol in fermentation samples with complex matrices has been developed using a gas chromatograph equipped with a head-space analyzer. A laser diffraction instrumental technique was developed to determine the particle sizes of various biomass samples.

We have also tried to enhance the scope of standard methods and verify methods for use with new biomass samples. For any protocol that has potential for becoming a routine analytical test, the final step is to document the procedure in LAP format. Six new procedures and six enhanced or expanded procedures were validated, documented, and distributed as additions to the CAT Task LAP Manual. Five standardized analytical methods have been incorporated as standard test methods by the American Society for Testing and Materials.

Major Project Reports: See bibliography.

Summary Date: September 1995

Process Integration

Directing Organization:

U.S. Department of Energy (DOE)
through the

National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Project Manager: J. Mielenz

Telephone: (303) 275-4489

Contractor:

National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Principal Investigators: C. Hatzis, F. Keller, and
Q. Nguyen

Telephone: (303) 384-6215

Contract Number: DE-AC04-83CH10093

Contract Period: 3/94-9/95

Contract Funding (Source):

FY 1994: \$ 440,000 (DOE)
FY 1995: \$1,525,000 (DOE)

Objective:

Ensure a fully integrated process functions reliably and economically when operated on realistic lignocellulosic feedstocks. Based on laboratory results, this work introduces operational realities that a fully integrated commercial process will face.

Approach/Background:

Our three-pronged approach is based on the need to obtain the engineering data to design a commercial process and to transfer this information to industry.

1. Based on performance data from the research program and process engineering needs from in-house and CRADA projects, perform conceptual process design and economic analysis to define the most economic processing options for a commercial facility
2. Conduct experiments that use realistic feedstocks in a fully integrated, bench-scale process that mimics the physical and chemical interactions in a commercial process
3. Guide the design, operation, and optimization of a pilot plant (process development unit), which will demonstrate a chemically and mechanically integrated biomass conversion process and develop

design data for the engineering demonstration unit.

Yellow poplar is the most abundant waste material from sawmill operation in the Ohio valley region, and the techniques developed with it can be readily transferred to other hardwood species and certain herbaceous materials; therefore, its sawdust was chosen as a standard feedstock for evaluation.

Status/Accomplishments:

In addition to bench-scale testing conducted under CRADAs, we worked on pretreatment and simultaneous saccharification and fermentation of yellow poplar sawdust.

Through a series of pretreatment, enzymatic hydrolysis, and fermentation experiments, standard methods were developed to store and handle feedstock and pretreated material to ensure comparison testing is done on the same basis. A quick method that uses epifluorescence was developed to monitor yeast cell viability. We are evaluating various techniques for detoxifying the inhibitors in wood prehydrolyzates.

Bench-scale fermentors, pretreatment equipment, and a batch prehydrolysis system were set up, and commissioning is under way. This system will improve the pretreatment capability and flexibility at bench scale.

A new and improved continuous stirred-tank bioreactor system was assembled. It can handle high solid loading, is sterilizable in place, and has on-line data acquisition and control. It will be integrated with the bench-scale pretreatment equipment and the Sunds hydrolyzer, and used for long-term continuous runs.

Major Project Reports: None.

Summary Date: September 1995

Process Development Unit (PDU)

Directing Organization:

U.S. Department of Energy (DOE)
through the
National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Project Manager: J. Mielenz

Telephone: (303) 275-4489

Contractor:

John Brown Engineers and Constructors
300 South Riverside Plaza
Suite 1100
Chicago, IL 60606

National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, CO 80401-3393

Principal Investigators: B. Duff, Q. Nguyen, and
G. Philippidis

Telephone: (303) 384-6862

Contract Number: YS-2-1161-1 and in-house

Contract Period: 3/94-9/95

Contract Funding (Source):

FY 1994: \$ 586,000 (DOE)
FY 1995: \$ 670,000 (DOE)

Objectives:

- Design, build, and operate a 1-ton-per-day biomass-to-ethanol facility that will be used to collect scaleup data to design a 40- to 100-ton-per-day biomass-to-ethanol engineering demonstration unit (EDU)
- Prepare the PDU for demonstration of the NREL Amoco CRADA process in the pilot plant.

Approach/Background:

NREL's integrated bench-scale research investigates chemical interactions among the biomass-to-ethanol process steps to determine overall process performance for small-scale equipment. However, this equipment is not large enough to accurately model a large commercial or near-commercial plant. This is especially true in technologies such as this one, in which solids are processed and recycling is necessary. The equipment size presents physical limitations on the range of operating conditions and physical pneumonia that can be investigated.

With the PDU, individual process steps and overall process configuration can be developed using equipment large enough to investigate a full range of realistic operating conditions and observe the various equipment-size dependent phenomena.

Because the eventual goal is commercialization, new ethanol production technology will be tested for NREL's industrial partners in the PDU.

Status/Accomplishments:

Phase II equipment was installed. Startup activities and initial experimental investigations are ongoing. Numerous modifications were made to improve operability, reliability, and capability. These include steam, air, process water, feedstock handling, pretreatment reactor, fermentor controls, and passivating stainless steel vessels to increase their corrosion resistance to the process fluid. Three experimental runs that incorporate pretreatment and SSF were successfully completed using hardwood and Amoco CRADA feedstock. The ethanol distillation was also tested successfully after an integrated run in early September 1995.

Phase III equipment is being designed and procured. The Phase III equipment will improve the operability and capability of the plant: aerobic capability for enzyme production, added cooling capacity, automated feed system for the pretreatment reactors, backup power system, fermentor exhaust condensers, chiller, larger cooling water system, clean in place system, and kill system for using recombinant organisms in the plant.

Major Project Reports: None.

Summary Date: September 1995

Feedstock Shredding, Storage, and Delivery in Support of the Process Development Unit (PDU) and Feedstock Knife Milling and Handling in Support of the Biofuels Program

Directing Organization:

U.S. Department of Energy (DOE)
through the
National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Major Project Reports: None.

Summary Date: September 1995

Project Manager: J. Mielenz

Telephone: (303) 275-4489

Contractor:

Hauser Chemical Research, Inc.
5555 Airport Boulevard
Boulder, CO 80301

Principal Investigator: K. Ammon

Telephone: (303) 443-4662

Contract Number: TCF-4-14177-01

Contract Period: 9/94-3/96

Contract Funding (Source):

FY 1994: \$131,815 (DOE)
FY 1995: \$ 98,250 (DOE)

Objective:

To receive, store, and shred lignocellulosic feedstock and ship to NREL as required for PDU operation. The subcontractor will also knife mill lignocellulosic feedstock and ship to NREL as required for other programmatic activities.

Approach/Background:

When operating, the PDU converts 1 dry ton per day of feedstock to ethanol, but it does not have enough space and equipment to handle large quantities of feedstock. This subcontract provides the intermediate staging steps necessary to ensure continuous feedstock delivery to the PDU. The subcontractor receives and stores feedstock, then shreds it (if required) and delivers it to the PDU at the required rate.

Status/Accomplishments:

The subcontractor has procured a warehouse facility for receiving and storing feedstocks. The shredder and knife mill have been installed and are operated by the subcontractor's personnel.

Biodiesel

Project Management, Market Development, and Public Outreach for Biodiesel

Directing Organization:

U.S. Department of Energy (DOE)
1000 Independence Avenue, SW
Washington, DC 20585

Project Manager: J.J. Sheehan

Telephone: (303) 275-4420

Contractor:

National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Principal Investigator: J.J. Sheehan

Telephone: (303) 275-4420

Contract Number: DE-AC02-83CH10093

Contract Period: 10/94-9/95

Contract Funding (Source):

FY 1995: \$70,900 (DOE)

Objective:

Establish strategic and operational plans for biodiesel, coordinate and support market development activities in the biodiesel industry and DOE, and increase public awareness of and support for biodiesel technology.

Approach/Background:

Biodiesel is a renewable diesel fuel substitute produced by chemically reacting an alcohol with a natural oil. The approach to DOE's biodiesel project has changed dramatically during the past 2 years. DOE's focus was on long-term research for biodiesel produced via microalgal conversion of waste CO₂ from fossil-fueled power plants to natural oils. This research is necessary in the long run to provide a resource base of natural oils sufficient to meet the needs of the transportation sector. The current project has both a short-term and a long-term focus. The near-term focus is on opportunities for biodiesel made from vegetable oil and animal fats.

Status/Accomplishments:

We have made great strides in developing a coordinated strategy for establishing a U.S. biodiesel industry. For the first time, we have a strategic plan that identifies several critical paths for biodiesel, and thus focuses our limited resources on activities most critical to achieving our goals.

Public support for biodiesel is increasing exponentially. Two years ago, biodiesel was virtually unheard of in the United States. Today, it is being tested in environmentally sensitive areas, and in niche markets such as mining, buses, government fleets, and marine use. Much of the increased interest is due to the efforts of the National Biodiesel Board (NBB). NREL has developed a working relationship with the NBB that allows each to leverage the other's limited R&D, market development, and outreach funds.

Major Project Reports: See bibliography.

Summary Date: September 1995

New Process Options for Biodiesel Conversion and Glycerol Utilization

Directing Organization:

U.S. Department of Energy (DOE)
1000 Independence Avenue, SW
Washington, DC 20585

Project Manager: J.J. Sheehan

Telephone: (303) 275-4420

Contractor:

National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Principal Investigator: J.J. Sheehan

Telephone: (303) 275-4420

Contract Number: DE-AC02-83CH10093

Contract Period: 10/94-9/95

Contract Funding (Source):
FY 1995: \$57,900 (DOE)

Objective:

Assess alternative process technologies for converting natural oils to biodiesel and using the glycerol by-product.

Approach/Background:

Biodiesel is a renewable diesel fuel substitute produced by chemically reacting an alcohol with a natural oil. When the natural oils are in the form of triglycerides, this reaction is known as transesterification, and is carried out today using basic catalysts such as NaOH or methoxide. Most transesterification processes do not work well with feedstocks that contain high levels of free fatty acids. The intent of this work is to identify processes that are more efficient than current conventional catalyst processes, and less sensitive to free fatty acid content. A more flexible process allows the use of a range of lower-cost feedstocks. The other major economic factor in converting natural oils to biodiesel is using glycerol. Even for niche applications, the volume of biodiesel production required to meet these small markets will result in a level of glycerol production that far exceeds current market demands. New, high-volume markets for glycerol are needed if it is to retain any value as a credit in the process.

Status/Accomplishments:

We have focused on developing enzymatic catalysts to improve the flexibility of the transesterification process. To this end, we are putting in place a three-way CRADA

with the USDA's Agricultural Research Service and the Fats and Proteins Research Foundation (FPRF) to collaborate on the initial evaluation of lipase enzymes as catalysts for transesterification. Researchers at USDA's Eastern Regional Research Center are conducting bench-scale experiments on biodiesel production using a variety of commercial lipase preparations. They have demonstrated that lipases exhibit much greater flexibility in handling a range of feedstocks that contain as much as 50% free fatty acids. FPRF, a nonprofit, private research organization, is supplying expertise on and samples from waste restaurant grease collection operations. NREL will use this information to establish the economic viability of enzymatic esterification with current commercial lipases.

We have also established a partnership with ARCO Chemical to evaluate the production of *di-tert-butyl* glycerol (DTBG) as a complementary fuel additive product derived from the glycerol by-product. ARCO has tested DTBG as an oxygenate for diesel fuel. We will analyze DTBG production, coupled with biodiesel production.

Major Project Reports: None.

Summary Date: September 1995

CO₂ Mitigation in Fossil Fueled Power Plants Using Microalgae with Coproduction of Biodiesel

Directing Organization:

U.S. Department of Energy (DOE)
1000 Independence Avenue, SW
Washington, DC 20585

Project Leader: J.J. Sheehan

Telephone: (303) 275-4420

Contractor:

National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, CO 80401-3393

Principal Investigators: K.L. Kadam and K. Zeiler

Telephone: (303) 384-6866

Contract Number: DE-AC02-83CH10093

Contract Period: 10/94-9/95

Contract Funding (Source):

FY 1995: \$67,000 (DOE)

Objective:

Establish a technoeconomic model of microalgae technology for CO₂ mitigation with coproduction of biodiesel.

Approach/Background:

Microalgae are unique photosynthetic organisms in that they accumulate high levels of natural oils, thrive in high-salinity water, and use CO₂ (an important greenhouse gas) as their sole carbon source. Microalgae grown in ponds can be used to trap CO₂ from power-plant flue gas while producing a feedstock for biodiesel.

Status/Accomplishments:

A spreadsheet-based economic model was developed for microalgae production using CO₂ from flue gases. This model predicts costs within 2% of those predicted by an earlier FORTRAN model, but is much easier to use. It has been used to assess targets for lipid content and growth rate of genetically engineered algae.

Because CO₂ collection is the single largest cost factor, we developed a model that predicts costs for recovering and delivering CO₂ from flue gas, in lieu of using market costs for CO₂. The process steps include monothanolamine (MEA) extraction, compression, dehydration, and transportation to the ponds. This approach yields a delivered CO₂ cost of \$41/mt, versus a market price of \$66/mt of CO₂. The model has also

shown that MEA extraction is 40% less expensive than the simpler route of direct flue gas utilization.

We have used our models to establish mid- and long-term targets for this technology. An improved process in the mid-term will result in a net cost \$20/mt of CO₂ mitigated. This is very competitive with other mitigation technologies. In the long term, we hope to identify process goals that reduce mitigation costs to zero, by reducing process costs and increasing biodiesel yields as a by-product credit.

Major Project Reports: See bibliography.

Summary Date: September 1995

Existing Technology Options for Production of Biodiesel from Low-Cost Feedstocks

Directing Organization:

U.S. Department of Energy (DOE)
through the
National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Project Manager: J.J. Sheehan

Telephone: (303) 275-4420

Contractor:

MARC-IV
6807 W. 202nd Terrace
Bucyrus, KS 66013

Principal Investigator: S. Howell

Telephone: (913) 681-0400

Contract Number: ACF-5-14418-01

Contract Period: 1/95-12/95

Contract Funding (Source):

FY 1994: \$25,000 (DOE)

Objective:

Determine technology options for producing and evaluating biodiesel from low-cost feedstocks at the pilot scale.

Approach/Background:

The cost of biodiesel produced from virgin soybean oil in the United States is \$2.50 to \$3.50 per gallon. This high cost remains the greatest obstacle to market penetration for biodiesel in blends or as a neat fuel. Three-quarters of the production cost is associated with the feedstock itself. Our work focuses on determining the feasibility of using lower-cost feedstocks, such as recycled cooking oils and waste from animal processing operations. We have joined forces with the Fats and Proteins Research Foundation and the National Biodiesel Board to conduct a technoeconomic analysis of conventional (off-the-shelf) technologies available today for processing these low-cost feedstocks, which have special processing issues. The greatest issue is the increased level of free fatty acids found in recycled materials. Once we identify technologies that can handle higher levels of free fatty acids, we will establish a plan to produce pilot-scale quantities of biodiesel made from these feedstocks. We will also test to establish the fuel's physical and chemical characteristics and their impact on engine and fuel performance.

Status/Accomplishments:

Preliminary results indicate a variety of technology options that can handle 10%–15% levels of free fatty acids in the feedstock. We would like to be able to handle higher levels of free fatty acid, but these technologies offer the opportunity to process waste restaurant grease and other materials. We have determined that pilot-scale operations, which negate the need for constructing our pilot plant, are available for producing biodiesel from these feedstocks. A final report from MARC-IV, which will be the basis for negotiating a subcontract for the next phase of research, is anticipated in early FY 1996. This will include producing and testing fuel.

Major Reports: None.

Summary Date: September 1995

Life-Cycle Assessment of Biodiesel

Directing Organization:

U.S. Department of Energy (DOE)

through the

National Renewable Energy Laboratory (NREL)

1617 Cole Boulevard

Golden, CO 80401-3393

Project Manager: J.J. Sheehan

Telephone: (303) 275-4420

Contractor:

Ecobalance, Inc.

1 Church Street

Rockville, MD 20850

Principal Investigator: J. Besnainou

Telephone: (301) 309-0800

Contract Number: ACG-5-15297-01

Contract Period: 8/95-5/96

Contract Funding (Source):

FY 1995: \$50,000 (DOE)

FY 1995: \$50,000 (USDA)

to include biodiesel via microalgal conversion of waste CO₂ to natural oils.

Status/Accomplishments:

To be worthwhile, an LCA must have broad-based input from all stakeholders. Thus, we built a consortium of biodiesel stakeholders to provide input on all assumptions, approaches, and system boundaries for the analysis. We have established a Biodiesel Working Group, an unprecedented collection of private and government interests that includes USDA, DOE, EPA, the City of Chicago, the National Biodiesel Board, Exxon, ARCO Chemical, Cargill, Twin Rivers Technologies, the Energy and Environmental Studies Institute, and the American Petroleum Institute. A scoping document has been drafted. We encourage anyone interested in providing input to contact the project manager.

Major Project Reports: None.

Summary Date: September 1995

Objective:

Produce an analytical tool for evaluating the energy, environmental, and economic benefits of producing biodiesel in the United States from lipid sources.

Approach/Background:

Life-cycle analysis (LCA) (first used by the Coca Cola Company 20 years ago) is now gaining world-wide prominence as a valuable tool for understanding the impacts of new products and processes on the environment and on corporate bottom lines. Such an analysis forces an assessment of the impacts of a given product from the extraction of any and all raw materials from the earth to the processing, distribution, and use of the product.

The definition of renewable fuels should be based on an LCA. The approach for this study is based on an exciting new set of software tools for LCA developed by Ecobalance. Thus, rather than simply producing a report on the life-cycle benefits of biodiesel, we will produce licensable software tools that companies and government entities can use to evaluate specific scenarios or product and process improvements for biodiesel.

Because of the near-term opportunities for biodiesel, this analysis will first focus on producing biodiesel from sources of natural oils. In the future, it will be expanded

Genetic Transformation of Microalgae for Enhanced Production of Natural Oils as a Feedstock for Biodiesel

Directing Organization:

U.S. Department of Energy (DOE)
1000 Independence Avenue, SW
Washington, DC 20585

Major Project Reports: See bibliography.

Summary Date: September 1995

Project Manager: J.J. Sheehan

Telephone: (303) 275-4420

Contractor:

National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Principal Investigators: T. Dunahay and
P. Roessler

Telephone: (303) 384-6280/384-6253

Contract Number: DE-AC02-83CH10093

Contract Period: 10/94-9/95

Contract Funding (Source):
FY 1995: \$167,000 (DOE)

Objective:

Develop genetic transformation systems for microalgae as tools for creating genetically engineered microalgae capable of enhanced natural oil production.

Approach/Background:

When grown in mass culture, microalgae can accumulate storage oil. They may therefore be an excellent feedstock for producing biodiesel fuel. The economics of producing biodiesel from microalgae would be significantly improved if microalgal strains with improved oil production characteristics could be developed. Genetic engineering can introduce these desirable characteristics into microalgae, but genetic transformation systems are not available for most microalgal species.

Status/Accomplishments:

We have developed a genetic transformation system for diatoms, an abundant group of microalgae with excellent potential for biodiesel production. This system is based on expressing a bacterial antibiotic resistance marker gene under the control of regulatory regions from an algal gene. Genetically transformed cells can be identified by their ability to grow in the presence of certain antibiotics. We have used this system to introduce additional native and foreign genes into the diatoms *Cyclotella* and *Navicula*. This represents a major advance in the field of algal biotechnology.

Biochemistry and Metabolic Engineering of Microalgae for Enhanced Biodiesel Production

Directing Organization:

U.S. Department of Energy (DOE)
1000 Independence Avenue, SW
Washington, DC 20585

Major Project Reports: See bibliography.

Summary Date: September 1995

Project Manager: J.J. Sheehan

Telephone: (303) 275-4420

Contractor:

National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Principal Investigators: P. Roessler and E. Jarvis

Telephone: (303) 384-6253/384-6147

Contract Number: DE-AC02-83CH10093

Contract Period: 10/94-9/95

Contract Funding (Source):

FY 1995: \$358,000 (DOE)

Objective:

Elucidate the biochemistry of microalgal lipid synthesis and develop metabolic engineering strategies for optimizing their production.

Approach/Background:

Creating genetically engineered microalgae with enhanced capabilities for producing biodiesel requires knowledge of the biochemical pathways that affect lipid accumulation. We hope to manipulate these pathways to alter the quantity and quality of lipids synthesized.

Status/Accomplishments:

We are investigating two approaches to enhance lipid production rates in microalgae:

1. Introduce additional copies of the gene that encodes acetyl-CoA carboxylase (ACCase), an enzyme that plays a key role in lipid synthesis (preliminary results show that microalgal cells genetically engineered in this manner have enhanced ACCase activity)
2. Reduce the rates of synthesis of other compounds, such as storage carbohydrates, to provide more substrate for lipid synthesis.

We have cloned an important gene involved in microalgal carbohydrate metabolism, which may be a target for inactivation.

Isolation of a Polyubiquitin Gene Promoter for Expression of Foreign Genes in Microalgae

Directing Organization:

U.S. Department of Energy (DOE)

through the

National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

characterize the promoter and terminator regulatory regions for use in microalgal gene expression systems.

Major Project Reports: None.

Summary Date: September 1995

Project Manager: J.J. Sheehan

Telephone: (303) 275-4420

Contractor:

George Mason University
4400 University Drive
Fairfax, VA 22030-4444

Principal Investigator: A. Christensen

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Contract Number: XCH-4-14406-01

Contract Period: 10/94-9/96

Contract Funding (Source):

FY 1995: \$44,698 (DOE)

Objective:

Isolate an algal ubiquitin gene and assess the ability of its regulatory regions to mediate foreign gene expression in microalgae.

Approach/Background:

A major focus of the biodiesel project at NREL is to investigate the use of microalgal lipids for producing biodiesel fuel. One goal is to optimize lipid production in microalgae by manipulating the flow of carbon into lipids via genetic engineering. The availability of promoters and other regulatory regions from a variety of algal genes will enhance our ability to accomplish this goal. Ubiquitin, a highly conserved protein, is expressed at high levels in many kinds of cells. The focus of this project is to isolate and characterize the regulatory regions from a microalgal ubiquitin gene and assess the ability of these gene sequences to mediate the expression of foreign genes in oil-producing microalgae.

Status/Accomplishments:

We screened a gene library from the diatom *Cyclotella cryptica* for the presence of ubiquitin gene sequences using a maize ubiquitin gene as a probe. We isolated and characterized a clone via restriction mapping and nucleotide sequencing. Preliminary results from the sequence analysis confirm the presence of an algal ubiquitin gene. We will analyze this clone to

Biosyngas

BioSyngas Product: Synthesis Research

Directing Organization:

U.S. Department of Energy (DOE)
1000 Independence Avenue, SW
Washington, DC 20585

Project Manager: D. Tyndall

Telephone: (303) 275-4483

Contractor:

National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Principal Investigator: S. Gebhard

Telephone: (303) 384-6249

Contract Number: in-house

Contract Period: 11/93-11/95

Contract Funding (Source):

FY 1994: \$ 121,000 (DOE)
FY 1995: \$ 121,000 (DOE)

Objective:

The goal of the Synthesis Task is to evaluate methanol, higher alcohols, and Fischer Tropsch catalysts for use with biosyngas in an integrated system. System integration is required to determine syngas conditioning performance, identify troublesome impurities and catalyst poisons, and evaluate fuel synthesis catalyst performance for a wide variety of biosyngas compositions.

Approach/Background:

Statistically designed experiments with bottled syngas and commercial or experimental fuels synthesis catalysts are used to explore the effects of hydrogen: carbon dioxide ratio, carbon dioxide, and methane concentrations, and contamination by select tar compounds on catalyst performance. Variable ranges span those encountered with biosyngas from different gasifiers. Slurry- and gas-phase processes are studied. Syngas conditioning is performed and poisons and impurities unique to biosyngas are determined by integrating a bench-scale synthesis reactor system with the thermochemical process development unit (TPDU) gasifier.

Status/Accomplishments:

A high-pressure, bench-scale, synthesis reactor system was built by TDA Research Inc. for NREL. It has a continuous stirred tank reactor in parallel with a tubular plug flow reactor. One reactor is used at a time

with up to five gas and two liquid feed streams. The system is pressure rated to more than 2500 psig and is under full computer process control. A second computer controls the gas chromatograph and sampling valve and collects data. A draft safe operating procedure supplied by TDA Research Inc. is being reviewed.

A syngas compressor was ordered to compress conditioned syngas from the TPDU gasifier. Three syngas conditioning methods will be available: water scrubbed, water scrubbed + steam reformed to remove methane, and hot-catalytically conditioned. The compressor outlet design pressure is 1600 psig and can be used for on-line synthesis or to fill gas cylinders for later off-line work (e.g., synthesis catalyst lifetime tests for which running the PDU for extended periods is impractical).

Designs have been started for the water scrubber and slip-stream catalytic syngas conditioning reactors that will interface the TPDU with the bench-scale synthesis unit.

NREL has signed confidentiality agreements with BASF and ICI-Katalco to test their commercial methanol synthesis catalysts. Catalyst samples have been obtained from BASF and United Catalysts Inc.; samples from ICI are forthcoming.

An extensive search of recent literature on higher alcohols synthesis catalysts was conducted. This information will be used to make syngas to higher alcohols catalysts at NREL for exploratory testing with biosyngas using the bench unit.

Major Project Reports: See bibliography.

Summary Date: September 1995

BioSyngas Product: Catalyst Development

Directing Organization:

U.S. Department of Energy (DOE)
1000 Independence Avenue, SW
Washington, DC 20585

Project Manager: D. Tyndall

Telephone: (303) 275-4483

Contractor:

National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Principal Investigator: S. Gebhard

Telephone: (303) 384-6249

Contract Number: in-house

Contract Period: 11/93–11/95

Contract Funding (Source):

FY 1994: \$ 214,500 (DOE)

FY 1995: \$ 214,500 (DOE)

Objective:

Develop a catalytic process that operates near gasification temperatures, eliminates tar and methane, and shifts the hydrogen:carbon monoxide ratio of biosyngas to make it suitable for methanol, higher alcohols, or Fischer-Tropsch synthesis.

Approach/Background:

Biomass gasification produces primarily hydrogen and carbon monoxide (syngas). Raw biosyngas must be purified and the hydrogen:carbon monoxide ratio increased before it can be used. Impurities include particulate matter, 1–2 vol % of highly aromatic tar, methane, and C₂ hydrocarbons. Conventional technology uses water scrubbing to remove tar followed by reheating to 750°C to destroy methane by steam reforming. Syngas conditioning removes tar and methane, and shifts the hydrogen:carbon monoxide ratio at 700°–800°C in one operation. Because syngas conditioning operates near gasification temperature, significant energy is saved.

Status/Accomplishments:

A baseline lifetime test with United Catalysts Inc. (UCI) G90B nickel steam-reforming catalyst was performed using model compound synthetic syngas with 50 vol % steam at 815°C. The catalyst remained active for 585 hours when the experiment was stopped.

A 2⁴ full factorial experiment that varied temperature (750°C and 800°C), steam content (30 and 40 vol %), nickel catalyst type (UCI G90B and experimental), and with/without alumina bed is in progress. Less than 50% steam was used to shorten the lifetime of the UCI G90B to test the effectiveness of the alumina upstream catalyst. The results from a 2² subset of the above experiment showed that when an alumina catalyst was used upstream of the nickel-based steam-reforming catalyst, methane and tar were destroyed, the hydrogen:carbon monoxide ratio was shifted from 0.6 to 2.5, and the lifetime of the nickel catalyst was increased by 500%. The water-gas shift activity of the alumina increases the hydrogen concentration of the syngas before it reaches the nickel catalyst bed. This is thought to explain the improved lifetime. The alumina bed is essentially inert to the hydrocarbons used in these experiments; consequently, the alumina did not deactivate.

Major Project Reports: See bibliography.

Summary Date: September 1995

BioSyngas Products: Gasifier Stream Characterization

Directing Organization:

U.S. Department of Energy (DOE)
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Washington, DC 20585

Project Manager: D. Tyndall

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Contractor:

National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Principal Investigators: S. Gebhard and
M. Ratcliff

Telephone: (303) 384-6249/(303) 384-6129

Contract Number: in-house

Contract Period: 11/93–11/95

Contract Funding (Source):
FY 1994: \$ 300,000 (DOE)
FY 1995: \$ 300,000 (DOE)

Objectives:

- Identify contaminants (tar, light hydrocarbons, and small quantities of nitrogen and sulfur compounds) in raw biosyngas
- Determine the effectiveness of catalytic conditioning.

Approach/Background:

Research to develop a catalytic process to condition syngas generated by biomass gasification has two components:

- Microscale catalyst tests with model synthetic tar and syngas under carefully controlled conditions
- Pilot scale engineering tests.

Two analytical methods are used to understand the composition of real biosyngas:

- Real-time mass spectral analysis using the NREL transportable molecular beam mass spectrometer (TMBMS)
- Analysis of condensed samples by gas chromatography/mass spectrometry (GC/MS). The TMBMS can identify high molecular weight compounds not analyzed by GC/MS.

Status/Accomplishments:

The TMBMS was used to monitor raw and filtered biosyngas from the Institute of Gas Technology (IGT) Renugas™ gasifier in Chicago, Illinois. Hot-gas filtering using Westinghouse technology was also monitored. Real-time quantitative concentration data on multiple chemical species found in the gasifier, tar-cracker, and hot filtered product streams were obtained. Tar produced by the IGT gasifier is principally tertiary in nature, in contrast to tar from the Battelle Columbus Laboratory gasifier, which is more secondary. The TMBMS data also provided real-time information that was used to smooth operation of the IGT gasifier's feeder.

Tar samples were obtained from slip-stream tests of five catalysts similar to DN34 using the Battelle Columbus Laboratory indirectly heated biomass gasifier. GC/MS analysis at NREL found approximately 95 compounds in the tar, of which 22 were quantified. All catalysts exhibited tar destruction activity. GC/MS data from the 133-hour DN34 lifetime test samples indicated little deactivation.

Major Project Reports: See bibliography.

Summary Date: September 1995

BioSyngas Products: Refinery Feedstock Research—Microactivity Test

Directing Organization:

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Contractor:

National Renewable Energy Laboratory (NREL)
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Principal Investigator: B. Rejai

Telephone: (303) 384-6198

Contract Number: in-house

Contract Period: 11/93–11/95

Contract Funding (Source):

FY 1994: \$ 269,500 (DOE)
FY 1995: \$ 269,500 (DOE)

Objective:

Use the principles of pyrolysis and catalytic deoxygenation to maximize the yield of hydrocarbon fuels from biomass.

Approach/Background:

The microactivity test (MAT) is a widely used research tool for catalyst screening in the petroleum refining industry. It is also an ASTM method. It has the advantage of allowing the collection of gaseous and liquid products and achieving mass balances higher than 95%. Our approach for screening catalysts, feedstocks, and operating conditions consists of rapid prescreening on the molecular-beam mass spectrometer (MBMS) followed by quantitative evaluation on the MAT unit.

Status/Accomplishments:

After successful completion of a MAT unit customized for biomass, catalyst screening for upgrading biocrude vapors is in progress. In the first phase of screening, several candidate catalysts, identified from the MBMS prescreening, were evaluated. The catalysts were compared under constant conditions of temperature and catalyst:biomass ratio.

We have identified two research catalysts that provided a significantly higher extent of deoxygenation than the commercial ZSM-5, under similar test con-

ditions. These research catalysts showed about a 20%–30% increase in the yield of gaseous and liquid hydrocarbons. Upon severe steam treatment, however, these catalysts lost significant deoxygenation activity. Once a catalyst with acceptable activity and selectivity is developed, means to increase its hydrothermal stability will be sought.

A commercial fluid catalytic cracking (FCC) catalyst was also evaluated on the MAT to confirm and quantify previous results. The catalyst gave a poor hydrocarbon yield and would likely need modifications or additives if biocrude were to be cofed to a refinery FCC in significant portions.

Other catalyst formulations that are synthesized in-house will also be evaluated. The results are then used by the Catalyst Synthesis Group for designing improved catalysts.

Major Project Reports: See bibliography.

Summary Date: September 1995

BioSyngas Products: Thermochemical Process Development Unit (TCPDU)

Directing Organization:

U.S. Department of Energy (DOE)
1000 Independence Avenue, SW
Washington, DC 20585

Project Manager: D. Tyndall

Telephone: (303) 275-4483

Contractor:

National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Principal Investigator: S. Phillips

Telephone: (303) 384-6235

Contract Number: in-house

Contract Period: 11/93-11/95

Contract Funding (Source):

FY 1994: \$ 539,000 (DOE)
FY 1995: \$ 884,000 (DOE)

Objective:

The Thermochemical Process Development Unit (TCPDU), located in the Field Test Laboratory Building high bay at NREL has been renovated and modified to operate in both a gasification and a pyrolysis mode at 0.5 tons per day. The first year of operation will be used to characterize the products produced at various operating conditions and to establish key operating parameters for producing syngas and pyrolysis oils from biomass. These products will be used by other tasks for additional experiments.

Approach/Background:

Gasifying biomass with oxygen or steam, or both, is a well-known operation that produces a medium-energy gas containing several products, including carbon monoxide, hydrogen, methane, and water. This gas is commonly known as dirty syngas, as it contains entrained solids such as char and other gas-phase contaminants such as high molecular weight products known as tars that condense at relatively high temperatures and act as poisons to catalysts used to make products from syngas, and vaporized alkali-containing compounds that can foul process equipment.

This syngas, which is representative of gas produced in commercial gasifiers, will be delivered to downstream unit operations intended to remove tars and

other potential poisons of catalysts used to make methanol or other synthesis products. The TCPDU will be able to produce syngas, test char and tar cleanup methods, and verify the effectiveness of the cleaning methods by using the "clean" syngas with commercially available synthesis catalysts.

In the pyrolysis mode, the TCPDU will be used to make whole pyrolysis oils from biomass; alternatively, the pyrolysis vapors can be directed through a catalytic riser cracker to be modified.

Status/Accomplishments:

The ability to remove char from a hot gas stream has been demonstrated during pyrolysis operations at NREL in FY 1994 and early FY 1995. The old process development unit had difficulty producing mass-balanced data and frequently had operational problems. These problems were addressed in the renovated TCPDU in the following ways: a rotary valve and accurate feeder control were added to the feeding system to improve feeding stability; char will be removed using cyclones, baghouses, or other filter media as experiments dictate; during pyrolysis operation, the pyrolysis vapors will be condensed in a three-stage indirect condensation process followed by an electrostatic precipitator, a coalescing filter, and a blower to remove any residual aerosols.

A new control system, networked with the analytical equipment, is being installed for improved data collection and reduction.

Major Project Reports: None.

Summary Date: September 1995

BioSyngas Products: Thermochemical PDU Analytical Support

Directing Organization:

U.S. Department of Energy (DOE)
1000 Independence Avenue, SW
Washington, DC 20585

Project Manager: D. Tyndall

Telephone: (303) 275-4483

Contractor:

National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Principal Investigator: M. Ratcliff

Telephone: (303) 384-6129

Contract Number: in-house

Contract Period: 11/94-11/95

Contract Funding (Source):

FY 1994: \$ 110,000 (DOE)
FY 1995: \$ 110,000 (DOE)

Objectives:

- Analyze the product streams that arise from operating the thermochemical PDU over the range of operating conditions from pyrolysis to gasification
- Monitor full-scale unit operations, with the goal of achieving a quantitative understanding of the chemistry of the entire process
- Ultimately, monitor key chemical species on-line for continuous process control.

Approach/Background:

The principal challenge of this project is representative, real-time sampling and analysis of the various product streams. No single analytical technique can provide the comprehensive detail required to fully characterize the chemistry of the process; therefore, a battery of analytical equipment with overlapping capabilities will be deployed for the various unit operations. The transportable molecular beam mass spectrometer will focus on continuous gas and vapor hydrocarbon determination from the raw and chemically upgraded pyrolysis and gasification streams. A Nicolet Fourier transform infrared spectrophotometer will enable major product gases and trace products such as ammonia and hydrogen sulfide to be analyzed on-line. Dedicated nondispersive infrared continuous chemical analyzers for CO, CO₂, and total hydrocar-

bons will also be used because they are industry standards and will provide a benchmark for the other analytical instruments. Portable, rapid analysis gas chromatographs (GCs) will perform other on-line gas analyses, especially hydrogen. Still other GCs and a high-pressure liquid chromatograph will be used for off-line condensed liquids analysis.

Status/Accomplishments:

All analytical equipment is either on hand or procured and awaiting shipment. The sampling systems are in the design and parts ordering phase, and required utilities are being installed. The sampling systems will be constructed soon, and will proceed in parallel with the final assembly of the process unit operations and interconnecting plumbing.

Major Project Reports: None.

Summary Date: September 1995

BioSyngas Products: Indirectly Heated Biomass Gasifier—Phase 2

Directing Organization:

National Renewable Energy Laboratory (NREL)
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Project Manager: D. Tyndall

Telephone: (303) 275-4483

Contractor:

Battelle Memorial Institute-Columbus Operations
505 King Avenue
Columbus, OH 43201-2693

Principal Investigator: M. Paisley

Telephone: (614) 424-4958

Contract Number: YM-2-11110-1

Contract Period: 11/93–11/95

Contract Funding (Source):

FY 1993: \$ 358,000

FY 1994: \$ 358,000

FY 1995: \$ 358,000

Status/Accomplishments:

Five syngas conditioning catalysts similar to DN34 were screened in slip-stream reactors at temperatures between 700°C and 870°C. Most had tar destruction activity similar to DN34 and all exhibited good to excellent water-gas shift activity. Methane destruction activity was poor in all cases. DN34 appears to be best among the catalysts tested to date.

Catalyst attrition is an important problem in the larger scale equipment. This is solved by having DN34 made in the required size rather than ground and screened as required now.

Initial gas turbine testing was successful. Small amounts of tar were transported to the compressor by entrainment in aerosol water droplets from the scrubber.

Major Project Reports: See bibliography.

Summary Date: September 1995

Objectives:

- Help develop commercially viable fuels from the indirect gasification of biomass
- Extend the hot-gas conditioning system database
- Provide an environmentally acceptable gas stream to fuel an unmodified gas turbine.

Approach/Background:

Biomass gasification produces a medium- to high-Btu product gas (syngas) that contains primarily hydrogen and carbon monoxide. The syngas is purified, then catalytically converted into methanol or hydrocarbon fuels. Raw syngas is too rich in carbon monoxide for direct use in fuels synthesis, which requires the hydrogen:carbon monoxide ratio to be increased and the 1–2 vol % of gasifier tar be removed. Conventional technology for tar removal is water scrubbing, which cools the gas to near ambient temperature. For interfacing indirect biomass gasification with the current commercial gas-phase methanol synthesis processes, the syngas must be reheated to 750°C to steam reform methane. An alternative to scrubbing is hot-gas conditioning. In syngas conditioning tar and methane are removed and the hydrogen:carbon monoxide ratio adjusted at near gasification temperature (850°C), which saves significant energy for the overall biomass-to-methanol process.

BioSyngas Products: Carbon Catalyzed Gasification of Organic Compounds

Directing Organization:

U.S. Department of Energy (DOE)
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Washington, DC 20585

Project Manager: D. Tyndall

Telephone: (303) 275-4483

Contractor:

National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Principal Investigator: M. Antal,
Hawaii Natural Energy Institute

Telephone: (808) 956-7385

Contract Number: XCF-5-14326-01

Contract Period: 11/93–11/95

Contract Funding (Source):

FY 1994: \$ 64,500 (DOE)
FY 1995: \$ 64,500 (DOE)

Objective:

Support thermochemical biofuels production research by developing a catalytic process for the complete, oxygen-free gasification of organic wastes in supercritical water.

Approach/Background:

Hydrogen-rich synthesis gas is produced from the gasification of organic materials in supercritical water 600°C, 34.5 MPa with carbon catalysts. Feedstocks investigated include glycerol (a waste product of biodiesel production), organic waste streams (methanol, methyl ether ketone, ethylene glycol, acetic acid, and phenol), sewage sludge, depithed bagasse liquid extract, and banana (*Musa sp. "Grand Main"*) tree stem. Most of these materials are available at low or negative cost, and some represent waste constituents in biofuels production. Supercritical water (T_c>374°C, P_c>22 MPa) is an excellent solvent for organic materials and is used as the reaction medium. Supercritical water reforms the organic feedstock over the carbon catalyst and produces a synthesis gas rich in hydrogen and methane. These can be used as fuel or to produce other biofuels such as methanol. These experimental studies employ a continuous flow reactor with a packed bed or catalyst.

Status/Accomplishments:

The carbon-based catalysts (including spruce wood charcoal, Macadamia shell charcoal, coconut shell, activated carbon, and coal activated carbon successfully gasified organic compounds in supercritical water. The University of Hawaii at Manoa agreed to pay for a patent application on the use of carbon catalysts as gasification agents in supercritical water.

Glycerol with a concentration as high as 2.0 M was completely gasified to hydrogen-rich synthesis sludge at 600°C, 34.5 MPa without carbon catalysts. Sludge was completely converted at the same condition with the carbon catalyst. The destruction efficiency for the organic wastes, including methanol, methyl ethyl ketone, ethylene glycol, acetic acid, and phenol, was high.

The effects of temperature and pressure on gasification were investigated systematically. A reaction temperature of 600°C or higher was required for complete gasification. Pressures higher than the critical pressure of water were necessary, but increasing the pressure further did not improve gasification efficiency.

Major Project Reports: See bibliography.

Summary Date: September 1995

BioSyngas Products: Gasification Products Characterization and Conditioning

Directing Organization:

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Washington, DC 20585

Project Manager: D. Tyndall

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Contractor:

National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
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Principal Investigator: S. Turn and S. Masutani,
Hawaii Natural Energy Institute

Telephone: (808) 956-7385

Contract Number: XCF-5-14326-01

Contract Period: 11/93-11/95

Contract Funding (Source):

FY 1994: \$ 147,000 (DOE)
FY 1995: \$ 147,000 (DOE)

Objective:

Support syngas conditioning research by providing information on the composition of raw gas produced in biomass gasification of conditioned gas following hot-gas filtering and catalytic reforming.

Approach/Background:

Much research has been performed on biomass gasification, but few studies have included comprehensive analyses of tars generated in biomass gasification, the influence of catalytic reforming conditions on gas composition, tar-conversion efficiency, or the evolution of fuel nitrogen in biomass gasification. Parametric tests were performed on a bench-scale biomass-syngas test system comprising a biomass gasifier, hot-gas filter, and catalytic reformer. Input variables are equivalence ratio and residence time; for the catalytic reformer they include temperature, space time, and steam:biomass ratio.

Status/Accomplishments:

The parametric tests on biomass gasification, using sawdust (a mixture of fir, poplar, oak, ash, and leucaena) as feedstock, identified tar species varied from single-ring to five-ring hydrocarbons. Under test conditions, tar yield and tar concentration in the product gas ranged from 15 to 64 g/kg biomass and 15 to 86 g/SCM, respectively. Lower temperatures

favor greater numbers of aromatic tar species with diversified substituent groups, and higher temperatures favored fewer aromatic tar species without substituent groups. Higher temperature or equivalence ratio favored polycyclic aromatic compounds. Oxygen-containing compounds existed in significant quantities only at temperatures lower than 800°C; among such compounds, phenol was most abundant.

Catalytic Reforming Tests. Under certain reforming conditions, 97% of the gasification tars were cracked (benzene and naphthalene were virtually eliminated) and gas yield and composition approached equilibrium. The commercial nickel-based catalyst tested here performed very well, but such catalysts have potential drawbacks vis-a-vis cost, intolerance to oxygen breakthrough, and disposal; the same experimental system used here can be used to examine alternative catalysts.

Parametric tests on the formation of nitrogenous compounds in biomass gasification, which used leucaena (a high-nitrogen content feedstock), showed that of the gasification process parameters varied here, fuel nitrogen products were most sensitive to gasification temperature, with ammonia (the prevalent fuel nitrogen derivative), nitric oxide, and nitrogen-containing tar species (collectively) decrease as gasification temperature increases, and hydrogen cyanide increases with increasing temperature.

Major Project Reports: See bibliography.

Summary Date: September 1995

Biocrude

BioCrude Products: Process Screening

Directing Organization:

U.S. Department of Energy (DOE)
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Washington, DC 20585

Project Manager: D. Tyndall

Telephone: (303) 275-4483

Contractor:

National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Principal Investigator: R.J. French

Telephone: (303) 384-6135

Contract Number: in-house

Contract Period: 11/93–11/95

Contract Funding (Source):

FY 1994: \$ 22,500 (DOE)

FY 1995: \$ 22,500 (DOE)

Objective:

Provide improved deoxygenation catalysts and understanding of the deoxygenation process that will lead to higher value fuel products from biomass pyrolysis.

Approach/Background:

In previous work, NREL's molecular-beam mass spectrometer (MBMS) was used to evaluate products from catalytic upgrading of plastics, municipal solid waste (MSW), and lignocellulosic biomass feedstocks. High yields of alkenes were produced by polyolefinic plastic, either pure or in MSW. These alkenes can be used to produce ethers for use as fuel additives such as methyl tertiary butyl ether. There is interest in exploring a wider range of catalysts, feedstocks, and conditions to improve the production of the most valuable fuel components from renewable feedstocks.

Status/Accomplishments:

About 30 metal-substituted zeolite catalysts have been examined by the MBMS. These produced varying amounts of products when used to upgrade biomass pyrolysis vapors. The relative amounts of alkanes, alkenes, single ring aromatics, multiple ring aromatics, alkyl-substituted aromatics, and oxides of carbon changed with the catalyst used. All these hydrocarbons have potential use as fuels, and the more promising catalysts have been identified for further testing on the microactivity test unit. Catalysts that

contain iron and cobalt gave higher overall yields of hydrocarbons than the reference HZSM-5 under the conditions tested, and those that contain copper or nickel, gave a more aromatic product slate. Many catalysts were much less active for removing oxygen from wood pyrolysis vapors than HZSM-5.

Most of these catalysts were synthesized in-house by ion-exchange, impregnation of organometallics, or surface modification of zeolites. New catalysts were evaluated by ammonia thermogravimetric analysis and gas chromatography analysis of reaction with model compounds and MBMS.

The workhorses of petroleum fluid catalytic cracking (FCC) are faujasite-Y zeolites. An example of this type of catalyst was evaluated for its effectiveness in upgrading wood pyrolysis vapors. Oxygen was only partially removed under the conditions tested, casting doubt on the efficacy of co-feeding raw biocrude to an FCC unit.

Hydrocarbon-rich feedstocks of various plant classes have been gathered. The product slates and yields will be compared for these plants.

Major Project Reports: See bibliography.

Summary Date: September 1995

BioCrude Products: Tetrahydrofurfuryl Alcohols and Tetrahydrofurfuryl Ethers

Directing Organization:

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Project Manager: D. Tyndall

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Contractor:

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Golden, CO 80401-3393

Principal Investigator: L. Moens

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Contract Number: in-house

Contract Period: 11/93-11/95

Contract Funding (Source):

FY 1994: \$ 70,000 (DOE)
FY 1995: \$ 70,000 (DOE)

Objective:

Convert the hemicellulose fraction of biomass into furfurals, which are subsequently hydrogenated to form tetrahydrofurfuryl alcohols (THFAs). The latter can be etherified to tetrahydrofurfuryl ethers (THFEs). THFAs and THFEs are potentially useful as new oxygenates for fuels.

Approach/Background:

Hemicellulosic liquors are first converted into furfurals (furfural and 5-hydroxyl methyl furfural) using acid catalysts. The current commercial process for converting pentoses into furfural usually results in low yields; therefore, new catalysts and catalytic systems are being explored. The challenge is to minimize the formation of polymeric by-products generated when furfural remains in contact with the acidic medium. The search for methods to allow furfural to be rapidly separated from the acid catalyst is receiving much attention.

The second step involves the search for efficient catalysts for hydrogenating furfurals, with the goal of achieving quantitative conversion, and to minimize hydrogenolysis of the newly formed THFAs. In parallel, alkylating THFAs to THFEs is being studied under heterogeneous catalytic reaction condition to obtain compounds with high octane numbers. The resulting substituted furan rings comprise a new class

of THFAs and THFEs with yet-unknown fuel properties.

Status/Accomplishments:

Using the NREL molecular beam mass spectrometer, a new catalyst (which generates furfural very efficiently from xylose at high temperature under dry conditions) was identified. This represents an interesting variation on the currently used aqueous media that contain sulfuric, hydrochloric, or phosphoric acid as catalyst. The nonaqueous reaction conditions open new possibilities for processing saccharide-rich mixtures. Because hemicellulose liquors cannot be dried to a solid material, the partial or complete hydrolytic depolymerization of hemicellulose into its monosaccharides will be attempted to obtain a crystallizable mixture. Alternatively, because the acid catalyst is unstable in an aqueous medium, a series of water-resistant catalysts (composed of organic and inorganic moieties) is being designed that can be applied to aqueous hemicellulosic liquors.

Major Project Reports: None.

Summary Date: September 1995

BioCrude Products: Hazen Operations

Directing Organization:

U.S. Department of Energy (DOE)
1000 Independence Avenue, SW
Washington, DC 20585

Project Manager: D. Tyndall

Telephone: (303) 275-4483

Contractor:

National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Principal Investigator: J. Scahill

Telephone: (303) 384-6196

Contract Number: in-house

Contract Period: 11/93-11/95

Contract Funding (Source):

FY 1994: \$ 138,500 (DOE)
FY 1995: \$ 138,500 (DOE)

Objectives:

- Continue to develop protective hardware to prevent severe erosion at the entrance to the vortex reactor from tramp material in realistic feedstocks. This includes developing hardware and methodology to periodically purge this inert material from the reactor.
- Produce significant quantities of high-quality biocrude oils in relatively high yields for use in other biocrude projects.

Approach/Background:

Realistic biomass feedstocks can be expected to have some amount of inert tramp material present (stones, dirt, etc.). This material must be removed from the vortex reactor; otherwise, it will cause severe erosion at the entrance to the reactor and upset the reactor fluid dynamics. Our approach is to develop a hardened replaceable wear plate for the reactor entrance to address the erosion and a diverter valve assembly that would be able to periodically purge the system of inert solids. With these devices in place, known amounts of tramp material will be introduced to the process while it is at operating temperature. Wear and efficiency of inert solids recovery will be measured to evaluate the designs.

The condensation train of the process will be modified to enable the rapid collection and recycling of pyrolysis liquids to the quench zone of the venturi scrubber

instead of having to start up with water in the scrubber. This is necessary to be able to produce a biocrude low in water.

Status/Accomplishments:

The condensation train has been modified. The transfer lines from the various receiving vessels were completely replumbed, and a gas recycle line and startup bypass line were added to the process flare to enable the condensation train to remain cool during startup. This also prevents the hot carrier gas from stripping volatiles from condensates when the feed needs to be discontinued for any length of time. Additional cooling capacity was also added to the venturi scrubber receiving vessel. These changes have improved the rate at which condensates accumulate and how soon the condensates can be recycled to the venturi throat.

Two pyrolysis experiments were conducted to produce biocrude oils. One used a conventional bag-house filter to separate char fines from the oils, and the other used a novel compact hot gas filter. Results will provide a comparison of the two designs' ability to produce oils in relatively high yields and the char separation efficiencies. Quantities of biocrude oils were also produced during these experiments. The wear plate and diverter valve assembly were designed, fabricated, and installed in the system, but have not yet been tested with abrasive materials.

Major Project Reports: None.

Summary Date: September 1995

BioCrude Products: Alternative Processes—Novel Ethers

Directing Organization:

U.S. Department of Energy (DOE)
1000 Independence Avenue, SW
Washington, DC 20585

Project Manager: D. Tyndall

Telephone: (303) 275-4483

Contractor:

National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Principal Investigator: J.O. Hoberg

Telephone: (303) 384-6130

Contract Number: in-house**Contract Period:** 5/95–11/95**Contract Funding (Source):**
FY 1995: \$50,000 (DOE)**Objective:**

To stabilize pyrolysis oils by reaction with methanol or ethanol forming ethers, esters, and acetals.

Approach/Background:

Pyrolysis oil stabilization uses two strategies:

- Treatment with methanol or ethanol and catalytic amounts of sulfuric acid. The reaction involves converting alcohols to ethers, carbonyls (aldehydes and ketones) to acetals $RC(OMe)_2$, and acids to esters. With the use of ethanol, forming and removing the esters along with water/ethanol via azeotropic distillation should be possible. This should leave an ether/acetal-enriched oil and enhance water removal.
- Identical conversions as stated above with an additional conversion of the acetal functionality to an ether. In the presence of acidic water, acetals can be hydrolyzed back to the carbonyl. Therefore, using a known method, complete conversion to an all ether oil via catalytic Pd/C should be feasible. The reaction uses hydrogen, methanol, and Pd/C to form acetals from carbonyl groups, then immediately transforms these to ethers.

Status/Accomplishments:

The current approach tests the method on commercial model compounds to obtain conversions and yields. It is then applied the pyrolysis oil using identical conditions. The products are analyzed with gas chromatography/mass spectroscopy and nuclear magnetic resonance.

For the first strategy, model compounds and pyrolysis oils were converted with low to good yields. The structure of the pyrolysis products was determined by comparison to the model compounds. The yields for the pyrolysis conversions were low, presumably because the high molecular weight compounds did not react.

For the second strategy, neither mixtures of model compounds nor pyrolysis oils were converted to the desired products. This failure can be attributed to equipment failure at the desired temperature and pressure or incompatible compounds in the pyrolysis mixtures.

Major Project Reports: None.

Summary Date: September 1995

BioCrude Products: BioCrude-Derived Diesel

Directing Organization:

U.S. Department of Energy (DOE)
1000 Independence Avenue, SW
Washington, DC 20585

Project Manager: D. Tyndall

Telephone: (303) 275-4483

Contractor:

National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Principal Investigator: F.A. Agblevor

Telephone: (303) 384-6244

Contract Number: in-house

Contract Period: 11/93-11/95

Contract Funding (Source):

FY 1994: \$ 75,000 (DOE)
FY 1995: \$ 75,000 (DOE)

Objectives:

- Modify biomass pyrolysis oils to improve their properties for cofeeding with heavy- and light-cycle oils in a fluid catalytic cracking (FCC) unit
- Determine the minimum degree of upgrading (partial hydrodeoxygenation, catalytic derivatization, and minimal deoxygenation) that will permit biocrude to be used in minimally altered diesel engines used in the transportation sector.

Approach/Background:

Straight biomass pyrolysis oils (noncatalytic and without hot gas filtering) are unstable, acidic, corrosive, viscous, and have high water and ash contents. These oils do not lend themselves readily to processing and upgrading in conventional petrochemical processes.

Using NREL's bench-scale fluidized bed reactor, which contains HZSM-5 and modified zeolite catalysts, biomass feedstocks are catalytically pyrolyzed to produce partially deoxygenated biocrude oils. In this approach, the pyrolysis and catalysis are carried out simultaneously, reducing coke yield and partially deoxygenating the pyrolysis products. The partially deoxygenated products can either be catalytically derivatized to methyl aryl ethers or co-fed with heavy-cycle oils to FCC units to produce oxygenated transportation fuels.

Status/Accomplishments:

Gram quantities of biocrude oils were produced from HZSM-5 catalyzed pyrolysis of biomass. The oils were partially deoxygenated and were miscible with heavy-cycle oils, but were immiscible with light-cycle oils. Catalyst coking was less than that for post-pyrolysis catalysis process.

Modified zeolite catalysts are being prepared for evaluation. They are expected to improve on the partial deoxygenation of the biocrude oils. Sulfate-impregnated γ -alumina catalysts are also being prepared for the vapor phase alkylation of the phenolics with methanol to produce methyl aryl ethers.

Major Project Reports: See bibliography.

Summary Date: September 1995

BioCrude Products: TCPDU Engineering and Experimental Design

Directing Organization:

U.S. Department of Energy (DOE)
1000 Independence Avenue, SW
Washington, DC 20585

Project Manager: D. Tyndall

Telephone: (303) 275-4483

Contractor:

National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Principal Investigator: J. Diebold

Telephone: (303) 384-6210

Contract Number: in-house

Contract Period: 11/93-11/95

Contract Funding (Source):

FY 1994: \$ 251,000 (DOE)
FY 1995: \$ 251,000 (DOE)

Objective:

Thermochemically convert biomass via fast pyrolysis to liquid biocrude fuels suitable for direct use in diesel engines, integration into a petroleum refinery, or a stand-alone or satellite fuel plant. This involves pyrolyzing biomass to oxygenated organic vapors, which can be condensed to form a high yield of an acidic fuel oil having very low sulfur and ash.

Approach/Background:

The oxygenated organic vapors are being upgraded by removing oxygen to form a hydrocarbon product slate. A riser reactor and catalyst regenerator, with a commercially available zeolite catalysts, is being uniquely close-coupled to the NREL 0.5 TPD, vortex pyrolysis reactor. Alkali poisoning of the zeolite catalyst is prevented by hot-gas filtering to remove the alkali-containing char from the process vapors prior to the catalytic riser. A series of statistically designed experiments will map out the product yields for the key process variables to determine the quantity and range of products available. These data will be used as input to process technoeconomic studies to determine the viability of this approach.

By participating in the IEA pyrolysis activity, we are developing specifications for biocrude oil, including test methods and allowable values. An international round-robin test series is being planned to validate the

test methods and specifications. The better grades of biocrude oils are expected to require the high quality of biocrude made with NREL technologies and know-how, such as hot-gas filtering.

Status/Accomplishments:

A series of experiments before the renovation demonstrated that the char fines could be very effectively removed by hot-gas filtration, but that there was a loss in biocrude yield to form gases in the hot-gas filter. The clean biocrude met the ash specifications of even ASTM #1 fuel oils. It also met the viscosity requirements of #4 fuel oil when new, but not after aging. Additives have been found that dramatically decrease the aging rate; this allows it to be stored for extended periods and still meet the viscosity specifications and to be heated before being atomized and combusted, e.g., in diesel engines.

Major Project Reports: See bibliography.

Summary Date: September 1995

BioCrude Products: Conversion of Lignins to Reformulated Gasoline

Directing Organization:

U.S. Department of Energy (DOE)
1000 Independence Avenue, SW
Washington, DC 20585

Summary Date: September 1995

Project Manager: D. Tyndall

Telephone: (303) 275-4483

Contractor:

National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Principal Investigator: J.S. Shabtai,
University of Utah

Telephone: (801) 581-5161

Contract Number: XAC-5-14411-01

Contract Period: 11/93-11/95

Contract Funding (Source):

FY 1994: \$ 51,000 (DOE)
FY 1995: \$ 51,000 (DOE)

Objective:

Depolymerize lignin to low molecular weight aromatics, then catalytically upgrade these cyclic compounds via hydrogenation, mild hydrocracking, and alkylation.

Approach/Background:

Experience from earlier work with lignites has shown that the latter can easily be converted into light liquid fuels via a two-step procedure. The lignite is first subjected to a mild hydrotreatment, followed by a base-catalyzed hydrolysis at high temperature. Work with lignin required some modification of this process, but very promising fuel compounds can be obtained.

Status/Accomplishments:

Numerous lignin feedstocks are subjected to a hydrolytic depolymerization process that generates good yields of mixtures composed of oxygenated aromatics with a high degree of ring alkylation. A new class of heterogeneous catalysts was synthesized and shown to be very active toward the hydrogenation of the aromatic compounds. A mixture of alkylated cyclohexanes has been obtained in good yields.

Major Project Reports: See bibliography.

Biofuels Feedstock Interface

Feedstock Interface

Directing Organization:

U.S. Department of Energy (DOE)
1000 Independence Avenue, SW
Washington, DC 20585

Project Manager: A. Wiselogel

Telephone: (303) 275-4466

Contractor:

National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Principal Investigator: A. Wiselogel

Telephone: (303) 275-4466

Contract Number: in-house

Contract Period: 10/92-9/93

Contract Funding (Source):

FY 1993: \$23,986 (DOE)

Objective:

Facilitate the interface between DOE-sponsored biomass feedstock development and conversion research efforts.

Approach/Background:

A biomass feedstock supply service was developed to provide NREL conversion research efforts with well-defined biomass feedstocks. A network of reliable feedstock producers and suppliers was established to obtain samples of feedstock materials ranging in size from 1 kg to 300 tons. Information on the samples is maintained by the project leader. Dry- and freezer-storage facilities were developed over the past 2 years and continue to expand as NREL research efforts expand and change.

Activities to improve the working relationship with the Biofuels Feedstock Development Program at Oak Ridge National Laboratory (ORNL) were outlined and initiated. By facilitating collaboration between the Biofuels Program at NREL and the Biofuels Feedstock Development Program at ORNL, overall research efforts of both programs will be improved. Developing formalized communications, collaboration on programmatic issues, and joint research efforts are being used to promote a coordinated research effort.

Status/Accomplishments:

The major users of the biomass feedstock supplying service have been the Alternate Pretreatment Subcontractors, NREL Chemical Analysis Testing Task, PDU vendor testing, various NREL thermochemical research efforts, and NREL pretreatment and fermentation researchers. Approximately 400 tons of biomass feedstocks were purchased and processed this year. Seven tons of switchgrass, 6 tons of corn stover, 5 tons of aspen, 2 tons of hybrid poplar, and 1 ton of paper have been obtained for research activities.

During FY 1993, the Terrestrial Biomass Feedstock Interface (TBFI) project and the Biofuels Feedstock Development Program have had representatives at their respective external reviews. This has given each group the opportunity to provide input to the other's operational and long-range planning efforts. Both have been involved in developing the DOE Biofuels Systems Division strategic planning efforts. Technical interactions include completion of a TBFI project subcontract on sycamore storage by ORNL, presentations by both at the other's reviews and workshops, having the same contact at the DOE Biofuels Systems Division level, and developing a feedstock production modeling subcontract for FY 1994.

Major Project Reports: None.

Summary Date: April 1994

Stakeholder Communications

Directing Organization:

U.S. Department of Energy (DOE)
1000 Independence Avenue, SW
Washington, DC 20585

Project Manager: A. Wiselogel

Telephone: (303) 275-4466

Contractor:

National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Principal Investigator: A. Wiselogel

Telephone: (303) 384-4466

Contract Number: in-house

Contract Period: 10/94-9/95

Contract Funding (Source):

FY 1995: \$50,000 (DOE)

Objective:

Facilitate effective communications between the Biofuels Program and external biomass stakeholders and customers.

Approach/Background:

The Terrestrial Biomass Interface (TBFI) project has aggressively developed working relationships with farmer and forestry professional and industrial organizations that represent potential biomass feedstock producers. Our participation with these organizations on issues of common concern has increased awareness of the Biofuels Program goals and objectives in the agricultural and forestry sectors. Awareness of the technical progress has been maintained through publications and presentations of research in scientific forums.

To obtain greater input from the private sector into the activities of the TBFI project, a guidance committee was formed in May 1995. The committee developed a charter and will meet biannually to provide input into research quality and direction.

Status/Accomplishments:

- Invited presentations and articles for farmer and forestry organizations have increased over the past year (National Association of Conservation Districts, New Uses Council, American Alfalfa Producers, California Urban Wood Waste Association, American Society of Agricultural

Engineers, American Society of Agronomy, Resource, Top Producers)

- Invited to testify before the House of Representatives Subcommittee on Conservation and Forestry
- Organized an external guidance committee consisting of representatives from private industry and academia.

Major Project Reports: See bibliography.

Summary Date: September 1995

Feedstock Services and Interface

Directing Organization:

U.S. Department of Energy (DOE)
1000 Independence Avenue, SW
Washington, DC 20585

Project Manager: A. Wiselogel

Telephone: (303) 275-4466

Contractor:

National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Principal Investigator: A. Wiselogel

Telephone: (303) 275-4466

Contract Number: in-house**Contract Period:** 10/94-9/95**Contract Funding (Source):**

FY 1994: \$72,000 (DOE)

Objectives:

- Provide a reliable resource of feedstock materials for Biofuels Program-sponsored research
- Facilitate the interface between DOE-sponsored biomass feedstock development and conversion research efforts.

Approach/Background:

A biomass feedstock supply service was developed to provide NREL conversion research efforts with well-defined biomass feedstocks. A network of reliable feedstock producers and suppliers was established to obtain samples of feedstock materials ranging in size from 1 kg to 2,000 tons. Information on the samples is maintained by the project leader. Dry- and freezer-storage facilities have been developed during the past 4 years and continue to expand as NREL research efforts expand and change.

Activities to facilitate the Biofuels Program's working relationship with the Biofuels Feedstock Development Program at Oak Ridge National Laboratory (ORNL) were outlined and initiated.

Status/Accomplishments:

The major users of the biomass feedstock supplying service have been the Alternate Pretreatment Subcontractors, NREL Chemical Analysis Testing Task, PDU vendor testing, various NREL thermochemical research efforts, and NREL pretreatment and fermentation researchers.

During FY 1995, the Terrestrial Biomass Feedstock Interface (TBFI) project and the Biofuels Feedstock Development Program had representatives at their respective external reviews. This has given each group the opportunity to provide input to the other's operational and long-range planning efforts. Both have been involved in developing the DOE Biofuels Systems Division strategic planning efforts. Technical interactions include completing a TBFI project subcontract on sycamore storage by ORNL, presentations by both at the other's reviews and workshops, having the same contact at the DOE Biofuels Systems Division level, and developing a feedstock production modeling subcontract.

Major Project Reports: None.

Summary Date: September 1995

Market Analysis on Near-Term Sources of Biomass Feedstocks

Directing Organization:

U.S. Department of Energy (DOE)
1000 Independence Avenue, SW
Washington, DC 20585

Project Manager: A. Wiselogel

Telephone: (303) 275-4466

Contractor:

National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Principal Investigator: S. Tyson

Telephone: (303) 275-4466

Contract Number: in-house

Contract Period: 10/92-9/93

Contract Funding (Source):

FY 1993: \$21,720 (DOE)

Objective:

Provide a market analysis (distribution, availability, and cost) for near-term biomass feedstocks identified by the ethanol, ethers, and syngas project leaders.

Approach/Background:

Develop a list of waste resources in conjunction with Biofuels Program managers and scientists. Prioritize the list based on near-term analytic needs of biofuels programs. Collect, evaluate, and summarize existing resource assessment information about wastes quantities, qualities, and values. Develop estimates for waste resources for paper and pulp mills, crop residues, and mixed waste. Construct a database of waste resources to determine favorable locations for near-term biofuel facilities. Identify information to help strategic planning and CRADA partners develop biofuels. Develop projections for future waste availability given competition within the energy markets and other markets for waste resources.

Provide a report or a series of issue papers describing opportunities for near-term biofuel development.

Status/Accomplishments:

Developed a selected list of feedstocks through meetings with program leaders. Developed a list of contacts made and delivered list to Amoco. Arranged contact between Amoco and interested municipal solid waste power developer. Developed inventory of material collected to date. Began construction of

electronic database for resource assessment. Prepared list of ethanol facilities. Presented program design and status to DOE/EE Sector Offices and the Regional Biomass Energy Program. Made contacts at a number of organizations to collect and review data. Drafted a report on supplies of paper and pulp mill residues; awaiting comments. Solicited comment on strategic plan for this project from program leaders.

Major Project Reports: See bibliography.

Summary Date: April 1994

Biomass Resource Assessment

Directing Organization:

U.S. Department of Energy (DOE)
1000 Independence Avenue, SW
Washington, DC 20585

Project Manager: A. Wiselogel

Telephone: (303) 275-4466

Contractor:

National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Principal Investigator: S. Tyson

Telephone: (303) 275-4466

Contract Number: in-house

Contract Period: 10/94-9/95

Contract Funding (Source):
FY 1993: \$80,000 (DOE)

Objectives:

- Provide a resource assessment (distribution, availability, and cost) for near-term biomass feedstocks identified by Biofuels Program leaders
- Work on developing a biomass database.

Approach/Background:

Develop a list of waste resources in conjunction with Biofuels Program managers and scientists. Prioritize the list based on near-term analytic needs of biofuels programs. Collect, evaluate, and summarize resource assessment information about wastes quantities, qualities, and values. Develop waste resource estimates for paper and pulp mills, crop residues, and mixed waste. Construct a database of waste resources to determine favorable locations for near-term biofuel facilities. Identify information to help strategic planning and CRADA partners develop biofuels. Develop projections for future waste availability given competition within the energy markets and other markets for waste resources. Provide a report or a series of issue papers that describe opportunities for near-term biofuels development.

Status/Accomplishments:

Developed a selected list of feedstocks by meeting with program leaders. Began constructing a biomass database in conjunction with the Resource Assessment Program's Biomass Resource Assessment Task and ORNL. This database can be accessed through the Resource Assessment home page. Presented program

design and status to DOE/EE sector offices and the Regional Biomass Energy Program. Made contacts at a number of organizations for data collection and review. Developed draft report on supplies of paper and pulp mill residues; awaiting comments. Solicited comments on strategic plan for this project from program leaders.

Major Project Reports: See bibliography.

Summary Date: September 1995

Standards Development and Rapid Analysis

Directing Organization:

U.S. Department of Energy (DOE)
1000 Independence Avenue, SW
Washington, DC 20585

Project Manager: A. Wiselogel

Telephone: (303) 275-4466

Contractor:

National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Principal Investigators: D.K. Johnson and
F. Agblevor

Telephone: (303) 384-6263/(303)384-6244

Contract Number: in-house

Contract Period: 10/94-9/95

Contract Funding (Source):
FY 1995: \$50,000 (DOE)

Objectives:

- Evaluate rapid analysis methods for use in determining biomass feedstock quality for conversion to liquid fuels by thermochemical and biochemical procedures.
- Develop accepted reproducible feedstock quality measurement methods.
- Develop National Institute of Science and Technology (NIST)-certified biomass materials.

Approach/Background:

Any industry must have methodologies and standard materials as baselines for comparing new methods and procedures. Standard practices and materials are also necessary to transfer a technology.

Rapid analysis techniques have near- and long-term applications. In the near term, they can replace the expensive, time-consuming laboratory analysis currently used to determine feedstock characteristics. In the long term, they can help determine feedstock value, so a feedstock vendor can be credited immediately for delivery. They can also monitor or control the quality of the feedstock going into a conversion reactor.

Status/Accomplishments:

Three rapid-analysis methods for quantifying the structural components in biomass are promising:

- Molecular beam mass spectroscopy, a very reliable analytical method at the laboratory level, is currently used as a rapid analysis technique at NREL
- Fourier transform infrared (FTIR) spectroscopy, coupled with partial least squares analysis, is used in the pulp and paper industry, and early results indicate that for woody biomass this system may work very well
- Near infrared (NIR) spectroscopy is used by the forage industry to measure forage quality. Preliminary work with subcontractors indicates that this system can work well with a wide variety of feedstocks.

The FTIR and NIR are scheduled for more rigorous evaluation.

Four biomass feedstocks (a hardwood, a softwood, sugar cane bagasse, and wheat straw) were established as standards and can be obtained from NIST. The task is initiating the certification of a switchgrass NIST material.

Major Project Reports: See bibliography.

Summary Date: September 1995

Feedstock Assessment

Directing Organization:

U.S. Department of Energy (DOE)
1000 Independence Avenue, SW
Washington, DC 20585

Project Manager: A. Wiselogel

Telephone: (303) 275-4466

Contractor:

National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Principal Investigators: D.K. Johnson and
S. Deutch

Telephone: (303) 231-7633

Contract Number: in-house

Contract Period: 10/92-9/93

Contract Funding (Source):
FY 1993: \$427,407 (DOE)

Objective:

Determine the importance of various sources of plant variability (genetic, environmental, physiological, and storage) on the composition of biomass feedstocks.

Approach/Background:

We studied compositional variability in biomass feedstocks relevant to the biofuels program. In addition to measuring the compositions of different species, this work also assessed the compositional differences between clones and varieties of the same species, as well as compositional variation caused by the conditions and climate under which the biomass was grown, harvested, and stored. The goal of this work was to obtain summative analyses. Data will be correlated with data from biochemical and thermochemical conversion processes and used to generate models that predict the effects of external parameters, such as growth and storage conditions, on biomass quality. This will improve our ability to quantitatively assess the cost of feedstock production, and lead to more accurate assessments of the overall cost of biofuels production.

Status/Accomplishments:

Compositional data have been collected on four woody and six herbaceous species, four of which were harvested at different times. These feedstocks were also part of a storage experiment that has generated data on the change in composition of

feedstocks subjected to unprotected storage for 26 to 52 weeks. Identified losses from the stored feedstocks were quite small, particularly for the structural components. The largest change observed across all species was loss of extractable materials (often more than 50%). This is an important issue in using these feedstocks for producing ethanol, particularly for herbaceous feedstocks where the extractives can contain a large fraction of fermentable nonstructural carbohydrate. All hardwoods were quite similar in composition, and changes in composition were small. In contrast, the compositions of herbaceous feedstocks varied substantially between harvests and species, and the effects of storage on composition were generally larger and more species dependent.

Descriptive modeling was used to obtain a global view of the total biomass database and to summarize the multivariable information collected. Predictive modeling was used to demonstrate how the various measurements may be used to predict the yields of fuels obtained from thermochemical and biochemical conversion of the feedstocks.

Major Project Reports: See bibliography.

Summary Date: April 1994

Feedstock Quality Model

Directing Organization:

U.S. Department of Energy (DOE)
1000 Independence Avenue, SW
Washington, DC 20585

Project Manager: A. Wiselogel

Telephone: (303) 275-4466

Contractor:

National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Principal Investigators: D.K. Johnson and
S. Deutch

Telephone: (303) 275-4466

Contract Number: in-house

Contract Period: 10/94-9/95

Contract Funding (Source):

FY 1993: \$76,000 (DOE)

Objectives:

- Determine the effects of storage on switchgrass composition
- Produce some necessary data to construct an empirical model that will provide information on feedstock quality.

Approach/Background:

This task provides empirical data to be used in developing a model that will help researchers, process engineers, and decision makers understand how biomass feedstock quality and composition changes under various handling strategies. Previous research has provided data on composition variability caused by genetics, cultural techniques, comminution, and storage. The work just completed looked at compositional differences between clones and varieties of the same species, and at compositional variation caused by the conditions and climate under which the biomass was grown, harvested, and stored. Work for the upcoming year is centered around samples from a sophisticated storage and handling experiment for switchgrass. The samples have been stored in a freezer and will be analyzed using rapid analysis techniques.

Status/Accomplishments:

Compositional data were collected on two major experiments (feedstock storage and plant variability).

These data, along with environmental and thermochemical data, were put into a database. Samples have been collected from a large switchgrass storage and handling experiment. Data on pretreatment and simultaneous saccharification and fermentation responses to various feedstock compositions are currently being obtained through a subcontract with Tennessee Valley Authority. Descriptive modeling was used to obtain a global view of the current biomass database. Predictive modeling was used to demonstrate how the various measurements may be used to predict the yields of fuels obtained from thermochemical and biochemical conversion of the feedstocks.

Major Project Reports: See bibliography.

Summary Date: September 1995

Thermochemical Conversion and Rapid Analysis

Directing Organization:

U.S. Department of Energy (DOE)
1000 Independence Avenue, SW
Washington, DC 20585

Project Manager: A. Wiselogel

Telephone: (303) 275-4466

Contractor:

National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Principal Investigators: D.K. Johnson and
F. Aglevor

Telephone: (303) 231-7633

Contract Number: in-house

Contract Period: 10/92-9/93

Contract Funding (Source):
FY 1993: \$220,746 (DOE)

Objective:

Determine the importance of various sources of plant variability (genetic, environmental, physiological, and storage) on the thermochemical conversion of biomass feedstocks into fuel precursors.

Approach/Background:

Study the variability in biomass feedstocks using rapid pyrolysis. This is performed on two scales. At an analytical scale using pyrolysis/mass spectrometry (Py/MS), large numbers of biomass samples can be screened in a short time. Multivariate analysis of the mass spectrometric data is then used to categorize the samples based on the chemical makeup of the pyrolysis products. Selected samples can then be pyrolyzed on a preparative scale in a fluidized-bed reactor, so enough product can be collected for chemical characterization to distinguish differences in the feedstocks based on their pyrolysis products.

A complementary effort is the development of rapid analysis techniques based on data-rich spectroscopic measurements, such as Py/MS, coupled with data reduction techniques such as multivariate analysis. In addition, standard materials and analytical methods for biomass are being established.

Status/Accomplishments:

Samples from the feedstock storage study, including four woody and six herbaceous species, four of which

were harvested at different times, have been examined using Py/MS coupled with multivariate analysis. Selected feedstocks were also pyrolyzed in the fluidized bed reactor. Chemical characterization of the oils showed that pyrolysis on the bench scale was very reproducible. Feedstock pyrolysis on both scales agreed that there were significant differences in the oils and chars produced from different species. However, there appeared to be little difference between the oils and chars from fresh and stored samples, when the stored material came from the major fraction of the stored biomass which had degraded to a limited extent. Analytical pyrolysis identified small fractions of more degraded material that did behave differently when pyrolyzed.

Two rapid-analysis methods have shown promise for quantifying the structural components in biomass. One is based on the analytical pyrolysis method used in screening samples in the feedstock storage study. The other uses Fourier transform infrared spectroscopy coupled with partial least squares analysis. Four biomass feedstocks (a hardwood, a softwood, sugar cane bagasse, and wheat straw) were established as standards and can be obtained from the National Institute of Science and Technology.

Major Project Reports: See bibliography.

Summary Date: April 1994

Effects of Storage on Eucalyptus

Directing Organization:

U.S. Department of Energy (DOE)
through the
National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Project Manager: A. Wiselogel

Telephone: (303) 275-4466

Contractor:

Bioenergy Development Corporation
888 Kalanianaole Avenue
Hilo, HI 96720

Principal Investigator: T. Crabb

Telephone: (808) 961-0411

Contract Number: AA-2-11210

Contract Period: 1/93-5/93

Contract Funding (Source):

FY 1993: \$15,784 (DOE)

Objective:

Determine the impacts of proposed storage methods on eucalyptus for the biomass-to-ethanol and thermochemical fuels research.

Approach/Background:

Because biomass production is seasonal and regional, there will be a need to store feedstocks for a certain length of time. The length of storage will be affected by the size of the conversion facility, its location, the number of feedstocks it will use, and the production characteristics of the feedstocks. During storage, various feedstock may undergo mass and compositional changes that affect the yield of the fuel produced. These changes, as a function of season, harvest method, and storage time, are being quantitatively assessed. Samples from these tests are being submitted to NREL for analysis, and to test the pretreatability and suitability of the substrates for conversion to ethanol or thermochemical-derived fuels.

Status/Accomplishments:

The storage phase was completed on schedule; all reports, biomass samples, and data have been received.

Major Project Reports: See bibliography.

Summary Date: April 1994

Dilute Acid Pretreatment and Simultaneous Saccharification and Fermentation (SSF) of Hybrid Poplar and Switchgrass

Directing Organization:

U.S. Department of Energy (DOE)
through the
National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Project Manager: A. Wiselogel

Telephone: (303) 275-4466

Contractor:

Environmental Research Center
Tennessee Valley Authority (TVA)
CEB 1C-M,
Muscle Shoals, AL 35660

Principal Investigator: M. Bulls

Telephone: (205) 386-3075

Contract Number: DAC-4-14212-01

Contract Period: 9/94–11/96

Contract Funding (Source):

FY 1994 \$150,000 (DOE)
FY 1995 \$102,000 (DOE)

Objective:

Determine the effects of genetic and environmental variability on pretreatment and simultaneous saccharification and fermentation (SSF) of hybrid poplar and switchgrass.

Approach/Background:

NREL is evaluating a range of herbaceous and woody plant materials to determine their potential as feedstock for ethanol conversion. There are several sections to this evaluation, including the effects of genetic and environmental variability on the ethanol conversion process; the effect of feedstock type on the ethanol conversion process; the pretreatability of feedstocks; and the fermentability of feedstocks after pretreatment.

Status/Accomplishments:

TVA has completed the evaluation criteria for approval necessary to start work on experimental samples. Currently, the first block of hybrid poplar samples are completing compositional, pretreatment, and SSF analysis.

Major Project Reports: See bibliography.

Summary Date: September 1995

Innovative Research for the Harvesting, Handling, Processing, and Storage of Sorghum

Directing Organization:

U.S. Department of Energy (DOE)
through the
National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Major Project Reports:

Summary Date: September 1995

Project Manager: A. Wiselogel

Telephone: (303) 275-4466

Contractor:

Agronomy Department
Iowa State University
Ames, IA 50011

Principal Investigator: I. Anderson

Telephone: (515) 294-9651

Contract Number: XAC-3-13279-01

Contract Period: 6/93-12/95

Contract Funding (Source):

FY 1993: \$35,149 (DOE)

Objective:

Determine the effects of proposed storage methods on sorghum for biomass-to-ethanol research.

Approach/Background:

Sorghum produces more carbohydrates and biomass per unit area of land than most crops. However, because of its short harvest time and high moisture and sugar content, it is stored as silage. Silage has several drawbacks as a storage method: anaerobic conditions need to be maintained; more than 70% of the weight is water; effluent disposal is a problem; and carbohydrates are lost.

To make sorghum a more attractive carbohydrate and biomass feedstock for conversion to ethanol, alternative harvesting, handling, processing, and storage systems need to be developed. An experiment designed to analyze the feasibility of dry storage of sorghum and to minimize sugar loss will provide some answers to the future feasibility of sorghum as an energy crop.

Status/Accomplishments:

Sorghum has been harvested using two methods: as piles of stocks and as bales of "press cake." Sorghum and sorghum extract samples were sent to NREL for analysis. Weather and storage environment variables are being measured and analyzed.

Effects of Ambient Environment on the Storage of Switchgrass in Iowa for Biomass-to-Ethanol and Thermochemical Projects

Directing Organization:

U.S. Department of Energy (DOE)
through the
National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Project Manager: A. Wiselogel

Telephone: (303) 275-4466

Contractor:

Iowa State University
Agronomy Department
Ames, IA 50011

Principal Investigator: I. Anderson

Telephone: (515) 294-9651

Contract Number: XAC-3-13277-03

Contract Period: 6/93-12/93

Contract Funding (Source):

FY 1993: \$49,449 (DOE)

Objective:

Determine the impacts of proposed storage methods on switchgrass for biomass-to-ethanol and thermo-chemical fuels research.

Approach/Background:

This subcontract is the last phase of a three-phase study to determine storage and handling impacts on feedstock quality. The first phase used several harvesting methods, the second focused on sources of variation in feedstock quality, and this phase will provide climatic information and supplemental handling data.

Status/Accomplishments:

Switchgrass has been harvested. The storage phase of the research is in its fifth month, and switchgrass samples from the first quarter-year of storage have been sent to NREL for analysis. Weather and bale environmental data are being collected and analyzed.

Major Project Reports: See bibliography.

Summary Date: April 1994

Preparation of Briefing Book of New Industrial Uses for Agricultural Commodities

Directing Organization:

U.S. Department of Energy (DOE)
1000 Independence Avenue, SW
Washington, DC 20585
through the
National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Project Manager: A. Wiselogel

Telephone: (303) 275-4466

Contractor:

New Uses Council, Inc.
1000 Executive Parkway, Suite 120
St. Louis, MO 63141

Principal Investigator: M. Dungan

Telephone: (314) 434-5556

Contract Number: AAR-5-15155-01

Contract Period: 12/94-6/95

Contract Funding (Source):

FY 1995: \$10,000 (DOE)

Objective:

Work with an established farmer-based organization to produce a document that facilitates the reevaluation of agricultural policies and programs from an energy perspective.

Approach/Background:

To broaden the awareness of individuals in the agricultural sector to the potential opportunities for biomass as a large-scale industrial crop, NREL participated with the New Uses Council to develop reliable information on nonfood and fiber crops. By working with an established organization with connections to farmers and large agriculture companies, the Terrestrial Biomass Feedstock Interface project's communication efforts were greatly enhanced. A briefing book was developed that contains papers by recognized experts, and public comments were obtained by holding a series of regional meetings.

Status/Accomplishments:

The briefing book was completed on time.

Major Project Reports: See bibliography.

Summary Date: September 1995

Seedling-to-Tailpipe Model

Directing Organization:

U.S. Department of Energy (DOE)
through the
National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Project Manager: A. Wiselogel

Telephone: (303) 275-4466

Contractor:

Biofuels Feedstock Development Program
Oak Ridge National Laboratory
P.O. Box 2008
Oak Ridge, TN 37831

Principal Investigator: M. Downing

Telephone: (615) 576-8140

Contract Number: DAC-4-14171-01

Contract Period: 8/94-12/95

Contract Funding (Source):

FY 1994 \$90,000 (DOE)

Objective:

Produce a feedstock production model that will supply direct input into liquid fuels process models developed by the Biofuels Program.

Approach/Background:

NREL process engineers have developed process spreadsheet models for producing ethanol from lignocellulosic feedstocks. These models require certain inputs and assumptions about the feedstock material going into the ethanol facility. Currently, many assumptions are educated guesses. To better understand the interactions between the feedstock variables with the conversion variables, we must create a model that includes all aspects of feedstock delivery and conversion.

Status/Accomplishments:

Tasks 1 through 3 are complete. Literature resources were obtained and feedstock production and handling strategies outlined. The remaining two tasks actually produce and test the model. An alpha version of the model has been tested and evaluated. The beta version is under development.

Major Project Reports: None.

Summary Date: September 1995

Effects of Storage on Hybrid Poplar (DN34)

Directing Organization:

U.S. Department of Energy (DOE)
through the
National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Project Manager: A. Wiselogel

Telephone: (303) 275-4466

Contractor:

University of Minnesota
1100 Washington Avenue, South, Suite 201
Minneapolis, MN 55415

Principal Investigator: W. Johnson

Telephone: (218) 281-6510

Contract Number: XA-2-11198-1

Contract Period: 1/93–6/93

Contract Funding (Source):

FY 1993: \$24,288 (DOE)

Objective:

Determine the impacts of proposed storage methods
on hybrid poplar for the biomass-to-ethanol and
thermochemical fuels research.

Approach/Background:

Because biomass production is seasonal and regional, there will be a need to store feedstocks for a certain length of time. The length of storage will be affected by the size of the conversion facility, its location, the number of feedstocks it will use, and the production characteristics of the feedstocks. During storage, various feedstock may undergo mass and compositional changes that affect the yield of the fuel produced. These changes, as a function of season, harvest method, and storage time, are being quantitatively assessed. Samples from these tests are being submitted to NREL for analysis, and to test the pretreatability and suitability of the substrates for conversion to ethanol or thermochemical-derived fuels.

Status/Accomplishments:

Completed storage phase on schedule; all reports, biomass samples, and data have been received.

Major Project Reports: See bibliography.

Summary Date: April 1994

Study of the Opportunities and Barriers to the Implementation and Sustainability of Bioenergy Systems

Directing Organization:

U.S. Department of Energy (DOE)
through the
National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Project Manager: A. Wiselogel

Telephone: (303) 275-4466

Contractor:

Scully Science Center
National Audubon Society
550 South Bay Avenue
Islip, NY 11751

Principal Investigator: J. Cook

Telephone: (516) 224-3730

Contract Number: ACD-5-15212-01

Contract Period: 7/95-7/96

Contract Funding (Source):

FY 1995 \$35,000 (DOE)

Objective:

Ensure timely analysis and interpretation of the changing attitudes to biomass power and biofuels development from an environmental perspective.

Approach/Background:

The overall thrust of integrated bioenergy systems has been viewed as a positive step for the environment, but there are still concerns about wildlife habitat and biodiversity impacts. These are now accepted as central to the debate about biomass energy development. A subcontract was placed with the Audubon Society to identify and outline potential points of conflict with the environmental community, and propose solutions.

Status/Accomplishments:

The tasks are:

- Help with ongoing roundtable activities
- Support the NREL Biomass Systems Integration activity issued by the Golden Field Office (DE-PS36-95G010052)
- Report on the environmental impacts of increased bioenergy use.

The principal investigator is attending roundtable meetings sponsored by Regional Biomass Energy Programs in the southeast and eastern United States. He is also helping with the Biomass System Integration effort.

Major Project Reports: None.

Summary Date: September 1995

Effects of Ambient Environment on the Storage of Switchgrass in Texas for Biomass-to-Ethanol and Thermochemical Projects

Directing Organization:

U.S. Department of Energy (DOE)
through the
National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

the bales indicated it does not differ from rain runoff obtained from pasture land. NIRS was used as a rapid analysis technique, and produced mixed results. The accuracy of NIR composition predictions may be increased by developing separate curves for hardwoods and grasses.

Project Manager: A. Wiselogel

Telephone: (303) 275-4466

Major Project Reports: See bibliography.

Contractor:

Texas A&M University Research Foundation
Box 3578
College Station, TX 77843

Summary Date: September 1995

Principal Investigator: M. Sanderson

Telephone: (817) 968-4144

Contract Number: XAC-3-13277-01

Contract Period: 6/93-5/95

Contract Funding (Source):

FY 1993: \$67,809 (DOE)

Objectives:

- Determine the effects of storage on switchgrass composition
- Determine biomass loss caused by harvesting and baling
- Determine the amount and constituents of runoff water from bales
- Develop an energy balance
- Study the use of near infrared reflectance spectrophotometry (NIRS) as a rapid-analysis technique to measure feedstock quality.

Approach/Background:

This subcontract is the last phase of a three-phase study to determine the storage and handling effects on feedstock quality.

Status/Accomplishments:

The results of this work indicate that losses of biomass during baling are about 1%–5%, depending on moisture; dry switchgrass has greater losses. There were no significant differences between outside storage treatments for the variables of weathered layer thickness and dry matter loss. Analysis of rain runoff from

Effects of Ambient Environment on the Storage of Switchgrass in Kentucky for Biomass-to-Ethanol and Thermochemical Projects

Directing Organization:

U.S. Department of Energy (DOE)
through the
National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Project Manager: A. Wiselogel

Telephone: (303) 275-4466

Contractor:

College of Agriculture
University of Kentucky
Lexington, KY 40546-0091

Principal Investigator: M. Collins

Telephone: (606) 257-7310

Contract Number: XAC-3-13277-02

Contract Period: 6/93-12/93

Contract Funding (Source):

FY 1993: \$45,000 (DOE)

Objectives:

- Determine the impacts of proposed storage methods on switchgrass for biomass-to-ethanol and thermochemical fuels research
- Determine the impacts of plant structure on drying rates.

Approach/Background:

This subcontract is the last phase of a three-phase study to determine the effects of storage and handling on feedstock quality. The first phase used several harvesting methods, the second focused on sources of variation in feedstock quality, and this phase will provide climatic information and supplemental handling data.

Status/Accomplishments:

Switchgrass was harvested and analysis of environmental and cultural impacts on drying rates is complete. The storage phase of the research is in its fifth month, and switchgrass samples from the first quarter-year of storage have been sent to NREL for analysis. Weather and bale environmental data are being collected and analyzed.

Major Project Reports: See bibliography.

Summary Date: April 1994

Effects of Ambient Environment on the Storage of Switchgrass in Virginia for Biomass-to-Ethanol and Thermochemical Projects

Directing Organization:

U.S. Department of Energy (DOE)
through the
National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Project Manager: A. Wiselogel

Telephone: (303) 275-4466

Contractor:

Department of Agricultural Engineering
Virginia Polytechnic Institute and State University
Blacksburg, VA 24061-0303

Principal Investigators: J. Cundiff and L. Marsh

Telephone: (703) 231-7603

Contract Number: XAC-3-13277-04

Contract Period: 6/93-3/95

Contract Funding (Source):

FY 1993: \$34,289 (DOE)

Objectives:

- Determine the effects of storage on switchgrass composition
- Determine the effects of rain damage on feedstock quality
- Determine biomass loss caused by harvesting and baling.

Approach/Background:

This subcontract is the last phase of a three-phase study to determine storage and handling effects on feedstock quality. The first phase used several harvesting methods, the second focused on sources of variation in feedstock quality, and this phase will provide climatic information and supplemental handling data.

Status/Accomplishments:

The study was completed in March 1995, and pointed out how important equipment costs are to the production cost of biomass crops. By maximizing equipment use, cost can be reduced approximately 40%. Other experimental results provide information and data on how storage affects dry matter loss and switchgrass quality.

The amount of weathering that occurred in a bale was not affected by wrapping material (string or net), and had reached maximum depth within the first 4 months. However, string-wrapped bales lost significantly more dry matter. Bales made with more than 22% moisture or wrapped with string had significant changes in composition based on acid detergent fiber and nondetergent fiber.

Major Project Reports: See bibliography.

Summary Date: September 1995

Energy System Geographic Mapping for the State of Wisconsin

Directing Organization:

U.S. Department of Energy (DOE)
through the
National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Project Manager: A. Wiselogel

Telephone: (303) 275-4466

Contractor:

Wisconsin Energy Bureau
P.O. Box 7868
Madison, WI 53707

Principal Investigators: D. Wichert

Telephone: (608) 266-7312

Contract Number: AAC-4-14370-01

Contract Period: 6/94-10/95

Contract Funding (Source):

FY 1994: \$15,000

Objective:

Develop the ability to adequately assess the compatibility of the energy infrastructure in Wisconsin to support renewable energy by establishing a state-wide energy information system.

Approach/Background:

As part of its resource assessment efforts, the Terrestrial Biomass Feedstock Interface (TBFI) project is developing biomass resource data on a national scale. Agencies from various states are the sources for much of the information needed to produce the national database. The state of Wisconsin is putting biomass data into a format usable at NREL. The TBFI project is helping with this process, and the state of Wisconsin is performing its own biomass resource assessment.

Status/Accomplishments:

The subcontract is on schedule for completion in October 1995. All technical tasks are complete and the draft report is being written.

Major Project Reports: None.

Summary Date: September 1995

Technical Evaluation and Planning

Biofuels Strategic Plan

Directing Organization:

U.S. Department of Energy (DOE)
1000 Independence Avenue, SW
Washington, DC 20585

Project Manager: J. Mielenz

Telephone: (303) 275-4489

Contractor:

National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, CO 80401-3393

Principal Investigator: P. Bergeron

Telephone: (303) 275-4432

Contract Number: in-house

Contract Period: 11/94-10/95

Contract Funding (Source):

FY 1995: \$92,000 (DOE)

Objective:

Draft a strategic plan for the Biofuels Program as a whole, and for each project in the program.

Approach/Background:

Strategic plans have been written annually for each project within the Biofuels Program. The previous version of the Biofuels Program Strategic Plan was simply a summary of the individual project plans. This year's was written as a separate, stand-alone plan that included the updated project strategic plans as appendices, and that discussed issues pertinent to the program as a whole.

Status/Accomplishments:

An NREL-reviewed program plan was completed and submitted to DOE in August 1995. It starts by putting the NREL Biofuels Program into the context of the DOE mission and the OTT strategy to carry out that mission for the transportation sector. It then describes the benefits to the country that a successful biofuels industry could accrue. These benefits include enhanced energy security, environmental quality, economic growth, enhanced science and technology base, and regional equity.

The vision and mission statements are taken from the DOE Biofuels Systems Program strategic plan—*Biofuels: At the Crossroads*. Windows of opportunity are identified that will aid in commercializing biofuels, and that do or will exist for specified periods

of time. Target costs that will make biofuels competitive with fossil fuels are included. Factors that could threaten the commercial success of biofuels are also presented, and include lowering the projected demand for oxygenates and the long-term price of oil. Goals and objectives are listed, as are strategies to achieve them while minimizing the risk of failure. The strategies are broken down into biofuels cost reductions, technology and product selection, and management. Finally, background information on the situation analysis is presented in an appendix.

Major Project Reports: See bibliography.

Summary Date: September 1995

International Energy Agency Bioenergy Agreement

Directing Organization:

National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Project Manager: C.J. Wallace

Telephone: (202) 651-7532

Contractor:

National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Principal Investigator: C.J. Wallace

Telephone: (202) 651-7532

Contract Number: In-house

Contract Period: 10/94-10/95

Contract Funding (Source):

FY 1992: \$145,000 (DOE)
FY 1993: \$145,000 (DOE)
FY 1994: \$250,000 (DOE)
FY 1995: \$250,000 (DOE)

Objective:

The United States belongs to the International Energy Agency's (IEA) Bioenergy Agreement, which provides a mechanism for participating countries to exchange information and coordinate ongoing research programs in bioenergy. The agreement includes cooperation in the areas of biomass production, harvesting, and conversion. Participation allows the United States to take advantage of extensive research in other countries, thus gaining access to a much larger base of information than it would have without the cooperation. This knowledge helps the United States leverage its research dollars. At present, the United States pays only about 10% of the total costs of this work and receives the benefit of having other countries pay the remaining 90%.

Approach/Background:

The United States has participated in the IEA Bioenergy Agreement since its inception in 1978. At present, 15 countries plus the European Union participate. The agreement consists of specific programs, called tasks, in four areas:

- Task XII—biomass production, harvesting, and supply
- Task XIII—biomass utilization
- Task XIV—municipal solid waste conversion

- Task XV—greenhouse gas balances.

Within each task are individual projects, called activities, which deal with topics such as bioconversion for ethanol production, thermal gasification, and pyrolysis for liquid products. The United States participates in all four tasks and in several activities within each task. In addition, the United States leads the conversion work of Task XIII. As the operating agent, the United States leads the technical program and administers the funds provided by the participants. NREL performs the operating agent function for Task XIII for 1992-1997.

Status/Accomplishments:

These funds will be used to (1) pay 1995 U.S. contributions to the IEA Bioenergy Agreement, (2) contribute to implementing the IEA Strategic Plan, which includes increasing industry participation, upgrading products, and increasing communication via the World Wide Web and Internet.

Major Project Reports: See bibliography.

Summary Date: September 1995

Screening Study for Sawmill Waste Biomass-to-Ethanol Production Facility

Directing Organization:

U.S. Department of Energy (DOE)
through the
National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Project Manager: J. Mielenz

Telephone: (303) 275-4489

Contractor:

Belcan Engineering Group, Inc.
10200 Anderson Way
Cincinnati, OH 45242

Principal Investigator: B. Speicher

Telephone: (513) 891-0972

Contract Number: ACI-4-14235-01

Contract Period: 2/95-9/95

Contract Funding (Source):

FY 1994: \$202,000 (DOE)

Objective:

Perform a screening study to investigate the technical and economic feasibility of processing hardwood sawmill waste into ethanol at a large-scale biomass-to-ethanol facility in the tri-state area of Kentucky, West Virginia, and Ohio.

Approach/Background:

DOE and NREL are interested in applying biomass-to-ethanol (BTE) conversion technology to convert lignocellulosic wastes—currently a burden to local and regional hardwood sawmills and businesses—into transportation fuels, thereby strengthening the economy in multiple ways. A subcontract was commissioned for a screening study to identify and evaluate a site or sites in the Kentucky, West Virginia, and Ohio area that would support the long-term operation of a financially attractive sawmill waste BTE facility.

Status/Accomplishments:

The subcontract is complete. Belcan Engineering screened and ultimately selected two sites from the target region for the BTE facility, one a "green-field" or grassroots facility and the other an "add on" or expansion to an existing corn ethanol facility. Belcan then estimated the construction and operation costs,

developed business pro formas to evaluate economic viability or solicit business investors, and outlined a schedule for construction, additional testing, and startup for each site. This work was compiled and forwarded to NREL in the subcontract final report issued for review in September 1995.

Major Project Reports: See bibliography.

Summary Date: September 1995

Preliminary Feasibility Analysis for Collocating Cellulosic Ethanol Plants with Biomass Power Facilities

Directing Organization:

National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Project Manager: C.J. Wallace

Telephone: (202) 651-7532

Contractor:

DynCorp EENSP, Inc.
4300 King Street
Alexandria, VA 23202-1508

Principal Investigator: R.M. Tshiteya

Telephone: (703) 998-3600

Contract Number: YCE-4-14117-01

Contract Period: 2/94-1/95

Contract Funding (Source):

FY 1994: \$115,000 (DOE)

Objective:

To assess the issues that surround the addition of a biomass-to-ethanol plant to a biomass-fired power generating facility. The analysis examines the technical feasibility of collocating both plants, and emphasizes the resulting technical, economic, and environmental benefits.

Approach/Background:

- The minimum biomass feedstock requirements of a power facility were determined so the amount dedicated for ethanol production affects no more than 10% of current daily usage
- Databases of biomass power facilities of 14 MW and greater were researched
- Likely biomass power facilities that sold power to the grid and were 14 MW or larger were identified. This resulted in identifying 150 candidate facilities.
- Several discriminatory criteria were developed to reduce the number of candidate power facilities from 150 to 34
- Further analysis focused on three states that contain 24 of the 34 remaining sites, representing the East and West Coasts, and the upper Midwest regions of the United States

- Additional criteria reduced the analysis to three sites, one each in California, Maine, and Michigan.

Status/Accomplishments:

Surveys were conducted to gather specific general and technical information on each selected power plant. Key technical requirements for designing and implementing an ethanol plant were identified. Site-specific improvements required for adding an ethanol plant to a biomass power plant were recognized. Synergies between ethanol and power plants, and the resulting benefits, were identified. The options of coupling the biomass ethanol plant to a biomass power facility, or operating it on a stand-alone basis, and the potential tie-ins of process energy and labor that could benefit or hamper the operation of ethanol and power plants, were examined. A spreadsheet model was developed that estimates capital and operating costs for all scenarios. Although this was only a preliminary approach, the results are promising, and the study shows a deeper analysis is sought.

Major Project Reports: See bibliography.

Summary Date: September 1995

Biomass Systems Integration Program

Directing Organization:

U.S. Department of Energy (DOE)
through the
National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Project Manager: J. Mielenz

Telephone: (303) 275-4489

Contractor:

Pacific International Center for High Technology
Research (PICHTR)
2800 Woodlawn Drive, Suite 180
Honolulu, HI 96822-1843

Principal Investigator: A.R. Trenka

Telephone: (808) 539-3868

Contract Number: ZAU-4-13326-03

Contract Period: 4/94-9/95

Contract Funding (Source):

FY 1994: \$198,318 (DOE)
FY 1994: \$250,000 (PICHTR Project Team)

Objective:

Determine whether an investment-worthy business could be based on the conversion of a dedicated feedstock to ethanol and electricity at the Ka'u sugar plantation on the Island of Hawaii.

Approach/Background:

The decline of the Hawaiian sugar industry, including the closing of plantations and mills, has made large tracts of land and infrastructure available for planting and evaluating selected crops. Warm temperatures and abundant sunlight create an environment that is almost ideal for cultivating biomass crops that might serve as dedicated feedstocks for producing energy related products. A project team was established to develop this effort. Team participants included PICHTR, Amoco Corporation, Cargill Incorporated, C. Brewer and Company Ltd., Hawaii Electric Light Company, Hawaiian Electric Company, the County of Hawaii, and the Hawaii State Department of Business Economic Development and Tourism.

The Ka'u sugar plantation and mill are owned by C. Brewer and Company Ltd. The primary focus of the subcontract was the use of the sugar crop or other crops with sufficient carbohydrate content to produce ethanol and electricity.

Status/Accomplishments:

The biomass sources evaluated included sugar cane, sorghum, napiergrass, leucaena, and eucalyptus. The focus was to identify a crop or crops that could be used as feedstock for the production process, and to determine whether it could be supplied at a cost consistent with providing the final product, at a profit, to the marketplace. The preliminary economic overview indicated, on the basis of yield per acre per year and projected production costs, that energy cane and napiergrass were the most promising biomass crops. A detailed analysis for producing these crops at the Ka'u site was completed.

Several technologies for converting biomass to ethanol and electricity were reviewed and compared. The most promising approaches were surveyed in detail, using the costs and operational considerations for the Ka'u site. To date, the evaluation and analysis, that PICHTR has performed, have not shown that sufficient profits could be generated at the Ka'u site to justify investing large amounts of capital in an emerging technology. Other sites in Hawaii might promise a more profitable technology.

Major Project Reports: See bibliography.

Summary Date: September 1995

Economic Development through Biomass System Integration in Central Florida

Directing Organization:

U.S. Department of Energy (DOE)
through the
National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Project Manager: J. Mielenz

Telephone: (303) 275-4489

Contractor:

University of Florida
Center for Biomass
P.O. Box 110940
Gainesville, FL 32611-0940

Principal Investigator: W. Smith

Telephone: (904) 392-1511

Contract Number: ZAU-4-13326-05

Contract Period: 4/94-4/95

Contract Funding (Source):

FY 1994: \$170,742 (DOE)
FY 1994: \$171,000 (U. of Fl. Project Team)

Objective:

Develop an integrated analysis of a dedicated feedstock supply system, and determine its applicability to a specific region (central Florida) and the available crops/conversion systems.

Approach/Background:

Reclaimed phosphate-mined land in central Florida has been identified as an area with potential for growing biomass crops. If fuel from biomass systems proves profitable, approximately 73,000 acres of land could be available for biomass production. Reducing the buildup of atmospheric CO₂ by recycling CO₂ is a major environmental benefit for biomass/energy production. Using waste streams to produce ethanol may be further exploited for producing methane or for direct combustion. Another possibility is producing animal feed.

Status/Accomplishments:

The crops identified as having the most potential for biomass production include the tall tropical grasses (sugar cane, energy cane, and elephantgrass—also called napiergrass); leucaena; eucalyptus; and slash pine. Crop yields vary according to soil type and range from a high of 22 dry tons per acre for sugar

cane on phosphatic clay soil, to a low of 9 tons per acre for two varieties of eucalyptus and slash pine. The crop with the lowest estimated production cost per dry ton was leucaena on phosphatic clay at \$3.45 per dry ton. The largest single cost component for biomass production was harvest costs. The most cost-effective harvest method appeared to be a high-capacity forage chopper.

The potential ethanol yield per dry ton of sugar cane was estimated to be 119 gallons. The current cost for converting cellulose to ethanol was estimated to be too high to be economically feasible. Further research has been proposed to develop methods for reducing the associated costs. The subcontractor has proposed that by finding multiple uses for a specific feedstock—perhaps sugar cane—the costs for additional processes can be dramatically reduced.

Major Project Reports: See bibliography.

Summary Date: September 1995

New Bern Biomass to Energy Project

Directing Organization:

U.S. Department of Energy (DOE)
through the
National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Project Manager: J. Mielenz

Telephone: (303) 275-4489

Contractor:

Weyerhaeuser Company
CC II-103
Tacoma, WA 98477

Principal Investigator: D.R. Raymond

Telephone: (206) 924-6850

Contract Number: ZAU-4-13326-04

Contract Period: 5/94-8/95

Contract Funding (Source):

FY 1994: \$234,303 (DOE)
FY 1994: \$409,000 (Weyerhaeuser Team)

Objective:

Evaluate both a biomass gasification combined cycle (BGCC) and a biomass-to-ethanol process that would use a specific mill site and be sized to satisfy the mill's steam, power, and integration needs.

Approach/Background:

Weyerhaeuser's New Bern, North Carolina, facility was selected for a high-efficiency, biomass-fueled power plant primarily because it cannot burn residual hog fuel (primarily bark) generated at the adjacent sawmill and chip export facility. To use the bark boiler, New Bern would have to spend significant capital on flue gas treatment. It currently purchases 470,000 bbl/year of fuel oil to meet process steam demands (natural gas is not available).

Weyerhaeuser Company and its industrial partners (Amoco Corporation, Carolina Power and Light, and Stone & Webster Engineering Corporation) determined the conditions under which biomass-derived power and liquid fuels production can be practiced in an environmentally supportive and sound business manner. The partners performed a project feasibility study on a 39-MW_e BGCC power facility to assess the economic merits of expanding biomass use to produce electric power or liquid fuels, or both. In addition, the

partners evaluated an attending project that incorporated an ethanol plant to assess the relative economic merits of liquid fuels and power.

The team evaluated alternatives at each stage and developed an integrated program that resulted in the most cost-effective production of ethanol and electricity from sustainable sources of biomass. A production concept and detailed costs to define an engineering demonstration unit were formulated.

Status/Accomplishments:

Based on the information developed in this study, and parallel evaluations performed by Weyerhaeuser and others, biomass gasification for use in power production appears to be technically viable. At the New Bern mill, options exist that would allow the technology to be tested at the commercial scale while serving the practical energy requirements of the mill. A staged project development plan provides for a low-risk and low-cost demonstration of a biomass gasifier as an element of a boiler modification program, then allows for timely expansion of power production by adding a combined cycle cogeneration plant.

Ethanol technology is at an earlier stage of development, but there appears to be a set of realizable site and market conditions that could provide for an economically attractive woody-biomass-based ethanol facility. Ethanol's market price, feedstock cost, and enzyme cost dramatically affect the projected profitability of such a plant. Additional process and project development work is required to reduce uncertainties and perceived risks before proceeding with future work.

Major Project Reports: See bibliography.

Summary Date: September 1995

Feasibility of Reducing Costs of Liquid Fuels and Electricity from Dedicated Biomass Feedstocks and Waste-to-Resource Management

Directing Organization:

U.S. Department of Energy (DOE)
through the
National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Project Manager: J. Mielenz

Telephone: (303) 275-4489

Contractor:

Wood Industries Company (WICO)
3145 South Mooney Boulevard
Visalia, CA 93277

Principal Investigator: K. Kaulfuss

Telephone: (209) 625-9426

Contract Number: AAC-5-13326-11

Contract Period: 10/94-9/95

Contract Funding (Source):

FY 1994: \$200,000 (DOE)
FY 1994: \$200,000 (WICO Project Team)

Objective:

Develop a plan for integrating biomass production and conversion technologies to produce liquid fuels and electricity.

Approach/Background:

This subcontract was undertaken to demonstrate the feasibility of converting lignocellulosic biomass materials into ethanol and electric power. WICO, a wood waste management, composting, and fuel supply company, is interested in developing dedicated feedstock supply systems (DFSS) that can be economically integrated with a liquid fuel conversion process and existing biomass-to-energy combustion systems. To accomplish this, costs associated with the conversion systems must be substantially reduced.

The study summarized here was commissioned to determine whether cost reductions associated with an integrated community and regional planning approach are adequate to make the project viable. The community and regional planning approach would integrate DFSS, using the most productive indigenous herbaceous and woody crops, with sewage treatment, municipal waste recycling and disposal, power and heat

cogeneration, and recycling of ash, manure, agricultural residues, and other biosolids, to achieve the required cost reductions.

Status/Accomplishments:

The subcontract is nearing completion. Reports have been generated that:

1. Provide project definition for integrating a biomass-to-ethanol (BTE) plant with an independent power producer (IPP) and a DFSS
2. Detail the proposed conversion technology
3. Evaluate the regional biomass supply availability
4. Detail a preliminary design and cost estimate for integrating the BTE with an IPP
5. Propose a preliminary business plan
6. Provide an environmental monitoring plan
7. Review the market conditions that could affect feasibility
8. Assess the socioeconomic and environmental factors that could affect the project's feasibility.

A final report that provides a detailed assessment of the project's viability and any additional research and project development needs required to support a decision to proceed is being prepared.

Major Project Reports: See bibliography.

Summary Date: September 1995

Strategic Planning for the Biofuels Systems Program

Directing Organization:

National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Project Manager: C.J. Wallace

Telephone: (202) 651-7532

Contractor:

DynCorp EENSP, Inc.
4300 King Street
Alexandria, VA 23202-1508

Principal Investigator: A.F. Alvarez

Telephone: (703) 998-3600

Contract Number: YCC-4-14117-01

Contract Period: 2/94-1/95

Contract Funding (Source):

FY 1994: \$75,000 (DOE)

Objectives:

- Reevaluate the Biofuels Systems Program (BSP) direction and interactions with industry and other stakeholders
- Incorporate strategic planning into BSP program management, budget formulation, technology transfer, and annual operations.

Approach/Background:

The U.S. Department of Energy (DOE) is refocusing its research from strictly long term to include commercializing technologies that benefit the strategic planning for all government programs. This activity by DynCorp EENSP was designed to help DOE's Biofuels Systems Division (BSD) develop a multiyear strategic plan for the Biofuels Program, including a total reevaluation of program direction and interactions with industry.

A series of workshops and meetings was held between BSD program managers and program managers from NREL and Oak Ridge National Laboratory. DynCorp EENSP strategic planning facilitators and writers guided the process during the workshops and meetings, and documented results. Three workshops and several meetings were conducted, during which draft vision, mission, goals, and objectives were developed. A situation analysis that examines the program's strengths, weaknesses, threats, and opportunities was also completed. Implementation strategies and action plans are now being developed.

Status/Accomplishments:

The initial phase of strategic planning was completed by making one BSP goals strategy "planning and management." A draft Biofuels Program Strategies Plan was completed and peer reviewed.

Major Project Reports: See bibliography.

Summary Date: September 1995

Information Management Assessment and Quality Improvement

Directing Organization:

National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Major Project Reports: See bibliography.

Summary Date: September 1995

Project Manager: C.J. Wallace

Telephone: (202) 651-7532

Contractor:

DynCorp•Meridian
4300 King Street
Alexandria, VA 23202-1508

Principal Investigator: A.F. Alvarez

Telephone: (703) 998-3600

Contract Number: YCC-4-14117-01

Contract Period: 2/94–1/95

Contract Funding (Source):

FY 1994: \$55,000 (DOE)

Objective:

Improve the quality of processes by identifying and categorizing the number, frequency, and types of information requests made to the Biofuels Systems Division (BSD) and assess the effectiveness of the current set of procedures used to respond to these requests.

Approach/Background:

Conduct a comprehensive review and evaluation of all phases of the BSD's response-recording-tracking systems, information processing procedures, correspondence controls, information distribution networks, and actuating processes. Assess BSD's effectiveness in planning, organizing, implementing, and controlling.

Status/Accomplishments:

The project is complete. There were five major findings and 23 recommendations for quality improvement.

Information Management Systems

Directing Organization:

National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Project Manager: C.J. Wallace

Telephone: (202) 651-7532

Contractor:

DynCorp EENSP, Inc.
4300 King Street
Alexandria, VA 23202-1508

Principal Investigator: J.L. Easterly

Telephone: (703) 998-3600

Contract Number: YCC-4-14117-01

Contract Period: 2/94-1/95

Contract Funding (Source):

FY 1994: \$14,000 (DOE)

Objective:

Help develop and implement standardized approaches for compiling biomass energy information required for the U.S. Department of Energy (DOE) Regional Biomass Energy Program (RBEP) planning, in coordination with the DOE Energy Information Administration (EIA).

Approach/Background:

RBEP-HQ, the five RBEP regional offices, and DOE-EIA are interested in having access to accurate, up-to-date information regarding institutional and industrial use of biomass at facilities across the United States. To help meet this need, DynCorp EENSP prepared an upgraded version of software it developed, called the Biomass Facility Information System (BFIS). This is a user-friendly relational database that compiles and displays information regarding biomass facilities in the utility, industrial, commercial, and institutional sectors. BFIS includes a facility mapping system that graphically displays the location (including state and county boundaries, major roads, and cities) of biomass energy facilities in the database. To help RBEP and EIA staff assess the merits and usefulness of BFIS, DynCorp prepared presentations and demonstrations of BFIS for the staff of RBEP, DOE-EIA, NREL, Tennessee Valley Authority (TVA), and the five RBEP regional offices; and participated in joint meetings and workshops for RBEP and DOE-EIA, to address biomass data collection requirements and issues.

Status/Accomplishments:

Presented a demonstration of BFIS at DOE on May 12, 1994, including a video display of the relational database and mapping features of the software.

Prepared and presented a briefing on BFIS for a workshop sponsored by RBEP and DOE-EIA to address biomass data collection requirements.

Major Project Reports: See bibliography.

Summary Date: September 1995

International Energy Agency Bioenergy Strategic Plan

Directing Organization:

National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Project Manager: C.J. Wallace

Telephone: (202) 651-7532

Contractor:

DynCorp EENSP
4300 King Street
Alexandria, VA 23202-1508

Technology & Management Services, Inc. (TMS)
18757 North Frederick Road
Gaithersburg, MD 20879

Principal Investigator: C.J. Wallace

Telephone: (202) 651-7532

Contract Numbers:

DynCorp EENSP: YAC-5-15099-01
TMS: YAC-4-14043-01
In-house

Contract Period: 1/94–1/95

Contract Funding (Source):

FY 1994: \$100,000 (DOE)

Objective:

In direct support of the shared goals adopted at the International Energy Agency (IEA) Ministerial Meeting of June 1993, the executive committee for the Bioenergy Agreement has promulgated a strategic plan. This plan provides a strategic approach for achieving the vision and mission of the Bioenergy Agreement, and summarizes the joint views of the member-country participants (currently 15 countries and the European Union) who collaborate in the Agreement. In addition, it seeks to motivate the participation of industry and other interested parties, and to broaden public awareness of and support for its activities.

Approach/Background:

The vision and mission concepts that emerged from the strategic planning process focus on overcoming the environmental, institutional, technological, and financial barriers to the near- and long-term deployment of bioenergy technologies. The importance of these concepts is emphasized by:

- The potential of widespread commercial application of biomass energy to help participating nations meet the shared goals of the IEA
- The evolutionary forces that support the enhanced use of bioenergy for sustainable development
- The difficulties and barriers that must be addressed to help make this vision a reality.

Status/Accomplishment:

These funds were used to develop and publish the IEA Bioenergy Agreement Strategic Plan 1995–2000.

Major Project Reports: See bibliography.

Summary Date: September 1995

The Role of the Regional Biomass Energy Program in Methane Recovery

Directing Organization:

National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Project Manager: C.J. Wallace

Telephone: (202) 651-7532

Contractor:

DynCorp EENSP, Inc.
4300 King Street
Alexandria, VA 23202-1508

Principal Investigator: J.L. Easterly

Telephone: (703) 998-3600

Contract Number: YAH-5-15099-01

Contract Period: 2/95-1/96

Contract Funding (Source):

FY 1994: \$30,000 (DOE)

Objective:

Help the Regional Biomass Energy Program (RBEP) summarize its past role and accomplishments in recovering methane from biomass, and identify potential future roles for RBEP in methane recovery.

Approach/Background:

Substantial input was obtained from RBEP's five regional managers regarding past RBEP projects and successes in recovering methane-for-energy at landfills, sewage treatment facilities, and on-farm anaerobic digestion facilities. Information was also collected on methane recovery efforts supported by other DOE programs, USDA, and EPA. A report was prepared that addressed the methane recovery opportunities and why they are important (specifically for landfills, on-farm animal manure, and sewage treatment facilities). Barriers to methane recovery and utilization were summarized; highlights of RBEP projects and successes in each methane recovery area were presented; brief descriptions of other federal methane recovery efforts were provided (the EPA/USDA AgStar Program; the EPA Landfill Outreach Program; and the DOE Landfill Methane Recovery initiative under Action #37 of the "Energy Partnership for a Strong Economy"). The report concluded with suggestions regarding the potential role RBEP can play in fostering methane recovery in coordinating and collaborating with other federal agencies.

Status/Accomplishments:

A draft report was submitted to the RBEP managers for review. Based on this review a final revised report was prepared and printed in time for distribution at the Second Biomass Conference of the Americas in Portland, Oregon, August 21-24, 1995.

Major Project Reports: See bibliography.

Summary Date: September 1995

Biomass Methanol

Directing Organization:

National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Project Manager: C.J. Wallace

Telephone: (202) 651-7532

Contractors:

DynCorp EENSP, Inc.
4300 King Street
Alexandria, VA 23202-1508

TMS, Inc.
18757 N. Frederick Road
Gaithersburg, MD 20879

Principal Investigators:

R.M. Tshiteya (DynCorp EENSP)
S. Zukor (TMS)

Telephone: (703) 998-3600 (DynCorp)
(301) 670-6390 (TMS)

Contract Numbers:

DynCorp. EENSP: YAH-5-15099-01
TMS: YAC-4-14043-01

Contract Period:

2/95-1/96 (DynCorp EENSP)
1/95-1/96 (TMS)

Contract Funding (Source):

FY 1995: \$125,000 (DOE)

Objective:

Provide information about the potential contributions thermochemical conversion of domestic biomass can make to the U.S. energy supply and to national economic and environmental goals. Specifically, to examine impacts of creating and implementing biomethanol into the transportation system. Changes in fuel prices and import levels were considered for overall impact on the U.S. economy.

Approach/Background:

Today, there is no commercial biomethanol plant in the United States. However, the technology to produce methanol from biomass is evolving. The only current commercial technology is represented by the Koppers-Totzek gasifier that was designed for coal; the Institute of Gas Technology (IGT) gasifier and the Battelle-Columbus gasifiers represent near-term technologies; and an advanced Battelle Columbus gasifier with hot-gas cleanup represents a near- to mid-term possibility.

The approach is to show how thermochemical biomethanol plants can be competitive in the United States without subsidies in the long term. The analysis looks at opportunities for collocating biomass processing with existing natural gas methanol plants, reducing the costs of the initial plants, and building them sooner than would otherwise be possible. Finally, the technical and nontechnical barriers to biomethanol market entry and growth are examined.

Status/Accomplishments:

Several industrial firms, including BrightStar, Eastman Chemicals, and Terameth, are interested in developing, implementing, and commercializing biomethanol activities. These initiatives need to be encouraged by more cooperative government/industry cost-shared projects to demonstrate successively larger, fully integrated thermochemical biomethanol production systems. More research is needed to develop an optimized dedicated biomass feedstock and to resolve numerous technical issues. An extension of the current tax credit beyond the year 2000 is necessary. The analysis shows that the long-term economics of a mature industry using dedicated biomass feedstocks are close enough to being competitive to warrant continued inclusion in the national R&D portfolio.

Major Project Reports: See bibliography.

Summary Date: September 1995

Feasibility Analysis: Transition from Grain to Cellulose-Ethanol

Directing Organization:

National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Project Manager: C.J. Wallace

Telephone: (202) 651-7532

Contractor:

DynCorp EENSP, Inc.
4300 King Street
Alexandria, VA 23202-1508

Principal Investigator: A.F. Alvarez

Telephone: (703) 998-3600

Contract Number: YAH-5-15099-01

Contract Period: 2/95-1/96

Contract Funding (Source):
FY 1995: \$60,000 (DOE)

Objective:

Investigate the feasibility of cellulosic feedstocks replacing grain feedstocks between the years 2000 and 2015 for producing ethanol as a major transportation fuel.

Approach/Background:

This is a joint study between DOE's Policy Office, the Biofuels Systems Program (BSP) and their contractors (NREL, Argonne National Laboratory, and DynCorp EENSP) in response to EPACT 502(b) and the BSP's Strategic Goal No. 3. The analytic approach will:

- Develop alternative demand scenarios to define the volume of ethanol in the market, whether driven by legislation, policy, or the market
- Project feedstock cost curves and ethanol plant economics for grain ethanol and cellulosic ethanol, assuming several conversion plant types

- Define a family of supply curves for grain ethanol and cellulosic ethanol using several plant types
- Aggregate the feedstock/plant-type supply curves into an industry supply curve
- Determine the least-cost mix of feedstocks and conversion plant types that will satisfy the demand as defined by various demand scenarios
- Defining barriers, such as the dramatic increase in imports of very low-cost methanol from countries such as Saudi Arabia (where the natural gas feedstock was considered a waste product), to the transition and policies to facilitate the transition.

Status/Accomplishments:

Work is in progress. DynCorp's role is to develop one or more of the following: ethanol demand scenarios, feedstock supply curves, ethanol supply curves, or investment criteria.

Major Project Reports: None.

Summary Date: September 1995

Planning, Progress, and Issue Analysis

Directing Organization:

National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401-3393

Project Manager: C.J. Wallace

Telephone: (202) 651-7532

Contractor:

Technology & Management Services, Inc. (TMS)
18757 North Frederick Road
Gaithersburg, MD 20879

Principal Investigator: L. Hughes

Telephone: (301) 670-6390

Contract Number: YAC-4-14043-01

Contract Period: 12/21/93-1/21/96

Contract Funding (Source):

FY 1994: \$132,000 (DOE)
FY 1995: \$180,000 (DOE)

Objectives:

- Develop a planning process for the Biofuels Program
- Identify and emphasize critical factors associated with one or more elements of probable technical success, product or systems development success, and the ability to achieve economic application and success through commercialization by the private sector
- Identify options for increasing private sector cost sharing
- Evaluate technical, economic, and market uncertainties, and identify means for their full or partial resolution
- Help NREL support program needs related to enhancing interactions with stakeholders and developing and implementing strategies to facilitate early commercialization and deployment of biofuels systems
- Establish effective working relations with trade associations and state and local governments
- Establish future industry commercialization of biofuel technologies
- Address an assessment of methanol from biomass.

Approach/Background:

As the field manager for the U.S. Department of Energy's (DOE) Biofuels Program, NREL supports major planning, programming, and special analyses to meet major needs of the program. These projects address major issues of concern to NREL and DOE.

Status/Accomplishments:

Projects for 1994 are complete and required reports were delivered. For 1995, the assessment of methanol from biomass is under way and scheduled for delivery in October 1995.

Major Project Reports: See bibliography.

Summary Date: September 1995

Biofuels Feedstock Development

Analysis of Feedstock Production and Environmental Systems in DOE Feasibility Studies

Directing Organization:

U.S. Department of Energy (DOE)
through the
Oak Ridge National Laboratory (ORNL)
P.O. Box 2008
Oak Ridge, TN 37831-6422

Project Manager: J.H. Cushman

Telephone: (423) 574-7818

Contractor:

Biofuels Feedstock Development Program (BFPD)
Oak Ridge National Laboratory
Oak Ridge, TN 37831-6422

Principal Investigator: M.E. Downing

Telephone: (423) 576-8140

Contract Number: N/A

Contract Period: N/A

Contract Funding Source: N/A

Objective:

Provide technical support to project cooperators (DOE, Electric Power Research Institute, National Renewable Energy Laboratory, industry, and research institutions) so they can determine the technical, environmental, and economic viability of tree and grass crops as dedicated feedstock supply systems (DFSS) for producing liquid fuels and electric power.

Approach/Background:

Because of the strong feedstock component inherent in the solicitation entitled "Economic Development through Biomass Systems Integration," BFDP was asked to provide expert advice and consultation. BFDP's involvement began with review of responses to the proposal and progressed to attendance at meetings and numerous phone conversations with sponsoring organizations and cooperators who were awarded contracts.

Status/Accomplishments:

Parameters were developed that fostered an understanding of how potential users of energy crops were expected to evaluate DFSS. Economic analyses of costs of producing, managing, and monitoring production systems, and feedstock integration into local and regional landscapes, were considered essential. These parameters also ensured feedstock costs and feedstock availability were evaluated in a standard

manner. By providing the expertise of an agricultural economist familiar with the development of supply curves for DFSS and knowledgeable about the difficulty and necessity of developing markets for feedstocks ensured consistent assessment tailored to each region or location. In addition, cooperators in each project were strongly advised to adhere to the guidelines set by the National Biofuels Roundtable when considering environmental effects from dedicated feedstock production systems.

BFDP's representative became familiar with the entire range of feasibility studies and clearly and accurately assessed the relationship between developing crop production technologies and developing conversion technologies.

Major Project Reports: None.

Summary Date: September 1995

Baseline Soils Study for the 1000-Acre Hybrid Poplar Energy Crop Demonstration Project

Directing Organization:

U.S. Department of Energy (DOE)
through the
Oak Ridge National Laboratory (ORNL)
P.O. Box 2008
Oak Ridge, TN 37831-6422

Project Manager: V.R. Tolbert

Telephone: (423) 574-7377

Contractor:

Forestry Sciences Laboratory
USDA Forest Service
5985 Highway K
Rhineland, WI 54501

Natural Resources Research Institute
5013 Miller Trunk Highway
Duluth, MN 55811

Principal Investigators: J.G. Isebrands and
W.E. Bergeson

Telephone: (218) 720-4296

Contract Number: DE-AI05-95OR22368

Contract Period: 5/95-3/96

Contract Funding (Source):
FY 1994: \$30,000 (DOE)
FY 1995: \$30,000 (DOE)

Objectives:

- Sample soils to characterize baseline physical and chemical properties of the plantation sites
- Permanently reference the sampling points to allow later resampling to determine crop-induced changes in soil characteristics
- Calculate water-holding capacity of the upper 5 feet of soil based on particle size distribution and organic matter content using relations developed from similar soils throughout Minnesota
- Rank the sites in terms of anticipated productivity-based parameters such as available water-holding capacity, organic matter, and total nitrogen.

Approach/Background:

Because of widespread interest in the role tree plantations may play in sequestering atmospheric carbon, we must establish reliable baseline data to assess long-term changes in soil carbon and other chemical characteristics that result from converting agricultural land to hybrid poplar. We must also begin

to develop reliable recommendations for selecting future planting sites based on soils data. This project samples recently planted hybrid poplar plantations and establishes permanent tree growth and soil sampling plots to remeasure changes at the micro-site level. Particular attention is given to quantifying the carbon content of surface soils.

Data gathered as part of this project will be integrated with similar data from other hybrid poplar plantations in Minnesota and Wisconsin to form a regionwide database from which to develop soil- and climate-based growth models.

Status/Accomplishments:

All 13 sites planted in 1994 were visited to assess plantation condition and develop a detailed sampling plan for each site. Tree growth on several sites was considered too variable to provide adequate long-term yield information. Differences in tree growth are confounded with differences in weed control that limit our ability to assess the response of trees to soil and site characteristics. The list of sites to be included in the sampling was modified. Sites to be measured now include a combination of sites planted in 1994 and 1995 in the Alexandria area and four plantations in central and northwestern Minnesota. The Alexandria project sites to be sampled now include the Dittes, Sonstegard, Kreyer, Rogeske, Eskelson, Gimble, Durst, and Stroot plantations. The remaining four plantations are located in central Minnesota (1) and northwestern Minnesota (3). Soil sampling on these sites will begin in November.

Major Project Reports: None.

Summary Date: September 1995

Bioenergy from Willow

Directing Organization:

U.S. Department of Energy (DOE)
through the
Oak Ridge National Laboratory (ORNL)
P.O. Box 2008
Oak Ridge, TN 37831-6422

Project Manager: G.A. Tuskan

Telephone: (423) 576-8141

Contractor:

The Research Foundation of the
State University of New York (SUNY)
1 Forestry Drive
Syracuse, NY 13210

Principal Investigators: L.P. Abrahamson and
E.H. White

Telephone: (315) 470-6777

Contract Number: 85X-SN766V

Contract Period: 04/93-03/96

Contract Funding (Source):

FY 1992: \$12,000 (DOE)
FY 1993: \$15,000 (DOE)
FY 1994: \$15,000 (DOE)
FY 1995: \$15,000 (DOE)

Objectives:

- Maintain and expand cutting orchards to propagate genetically improved willow clones in nurseries for future scale-up
- Continue to develop strategies to establish hybrid willow bioenergy farms in the northeastern United States.

Approach/Background:

The first objective will be met by maintaining an intensive field management program in willow cutting orchards established during 1993, including fertilization, weed control (if necessary), and irrigation (where possible). A willow cutting orchard was established during 1995 in cooperation with the New York State Energy Research and Development Authority and the New York State Department of Environmental Conservation (NYDEC) at the NYDEC Saratoga Tree Nursery, Saratoga, NY. The second objective will be met by hosting and attending meetings with experts on renewable energy from local, regional, and national organizations to form a consensus on how dedicated willow plantations fit into the overall energy supply of the northeastern United States.

Status/Accomplishments:

Nursery stool beds at Orono, Ontario, and Syracuse, NY, grew vigorously during 1995. Growth in the Tully, NY, cutting orchard was not as good as anticipated because of the exceptionally dry 1995 growing season. The projected cutting yield during 1995 is conservatively estimated at 10,000 cuttings from each of 15 willow clones. A willow cutting orchard with an overhead irrigation system was planted with 15 willow clones in the NYDEC Saratoga tree nursery at Saratoga, NY, during 1995. Initial growth and survival appeared good. The clone-site trials planted during 1993 at Massena, and Tully, NY, were not harvested for cuttings during Winter 1994-1995 because enough cuttings were available from other sources.

We continued to develop strategies for establishing hybrid willow farms in the northeastern United States. Funding was approved from USDA CREES for extension activities and a 60-100-acre willow demonstration farm. A proposal submitted to the DOE/USDA Biomass Power for Rural Development program was favorably reviewed, and the negotiation process is expected to begin soon. Local utility companies increased their involvement in the SUNY ESF willow biomass program by funding field trials and a full-time researcher and helping to develop commercialization strategies. The Salix Consortium increased its membership to include utility companies from Pennsylvania, Vermont, and Ontario (Canada), Resource Conservation and Development projects, other universities, state and federal organizations, and a farm group.

Major Project Reports: See bibliography.

Summary Date: September 1994

Biochemical Basis of Drought Tolerance in Hybrid *Populus* Grown under Field Production Conditions

Directing Organization:

U.S. Department of Energy (DOE)

through the

Oak Ridge National Laboratory (ORNL)

P.O. Box 2008

Oak Ridge, TN 37831-6422

Project Manager:

G.A. Tuskan

Telephone: (423) 576-8141

Contractor:

Oak Ridge National Laboratory

Oak Ridge, TN 37831-6422

Principal Investigator:

T.J. Tschaplinski

Telephone: (423) 574-4597

Contract Number:

N/A

Contract Period:

10/94–9/96

Contract Funding (Source):

FY 1994: \$200,000 (DOE)

FY 1995: \$200,000 (DOE)

Objectives:

- Determine the degree of genetic variability in and limits of drought tolerance in poplar (*Populus*) clones
- Characterize the biochemical and molecular bases of drought tolerance in a poplar pedigree
- Develop biochemical and molecular screening procedures.

Approach/Background:

After establishing a Cooperative Research and Development Agreement with ORNL, Boise Cascade Corporation established a drought stress facility at Boardman, OR, with the University of Washington *Populus trichocarpa x deltoides* segregating F2 pedigree used to generate a molecular map of the poplar genome. Water was turned off every other day in one of the four replicate blocks to institute water stress. A survey of osmotic potential at full turgor (D_o) was conducted on well-watered and droughted trees. Some plant species, and some individuals within a plant species, can tolerate increasing stress associated with reduced moisture by accumulating solutes. The biochemical matrix of such metabolites varies among species and individuals. The study assesses drought stress under field conditions and characterizes changes in osmotic constitution among operational clones across three moisture levels, and experimental

(segregating F2 pedigree) clones under two irrigation regimes.

Status/Accomplishments:

The survey of osmotic potential at full turgor (D_o) of the F2 pedigree demonstrated tremendous variability among the full-sib progeny with D_o ranging from a high of -1.38 MPa (least tolerant) for clone 331-1120 to a low of -2.35 MPa (most tolerant) for clone 331-1087 under well-watered conditions. Under dry conditions, D_o ranged from a high of -1.40 MPa for clone 331-1120 to a low of -2.15 MPa for clone 331-1075, because of a 0.30 MPa adjustment. Having low D_o under wet conditions was advantageous at this site, with clones that had D_o of <-1.90 MPa under wet or dry conditions generally displaying greater productivity than those with D_o that was >-1.70 MPa. Of the eight clones that displayed statistically significant adjustments of 0.16–0.35 MPa, all were medium- to fast-growing. Except for clone 331-1075, all clones that displayed osmotic adjustment to water stress did so from high D_o under well-watered conditions. Genetic linkage mapping indicated several quantitative trait loci (QTLs) for D_o , including one on each of linkage groups O, M, and P, with each accounting for about 20% of the phenotypic variation in D_o under wet conditions. The same QTLs on M and P were recapitulated for D_o under dry conditions and an additional QTL on linkage group A was found, with the three markers explaining 98.7% of the phenotypic variation in D_o . Additionally, a QTL for osmotic adjustment was found on linkage group D, with overdominance indicated. When analyses of metabolites constituting D_o are complete, the maintenance and accumulation of key stress solutes will also be mapped. The first-year results are promising and suggest that biochemical and molecular markers for drought tolerance in poplar will be identified.

Major Project Reports: See bibliography.

Summary Date: October 1994

Bird and Small Mammal Use of Hybrid Poplar Plantings in Minnesota

Directing Organization:

U. S. Department of Energy (DOE)
through the
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Project Manager: V.R. Tolbert

Telephone: (423) 574-7377

Contractor:

North Central Forest Experiment Station
U.S. Forest Service
1992 Folwell Avenue
St. Paul, MN 55108

Principal Investigators: D.P. Christian,
J.M. Hanowski, and G.J. Niemi

Telephone: J.M. Hanowski: (218) 720-4311

Contract Number: DE-AI05-92OR22051

Contract Period: 9/92-9/96

Contract Funding (Source):

FY 1992: \$55,000 (DOE)
FY 1993: \$65,000 (DOE)
FY 1994: \$65,000 (DOE)
FY 1995: \$65,000 (DOE)

Objectives:

- Evaluate the suitability of short-rotation hybrid poplar plantations for breeding birds and small mammals
- Assess the effects of plantation size and shape on breeding birds within and adjacent to plantations
- Conduct a similar survey on nearby land for comparison.

Approach/Background:

Because birds and small mammals differ in their mobility and relationship to vegetation structure, these studies provide broader insight into the quality of habitat provided by woody crop plantings than study of one taxon alone. Breeding bird surveys were conducted on research-scale plantings in Minnesota, North Dakota, and Wisconsin from 1992 to 1994 to compare community and species composition between plantings, agricultural row crops, pastures/haylands, and wildlands. Studies were expanded in 1994 and 1995 to include large-scale plantings of 50 to 300 acres of hybrid poplar. Small mammals were monitored on

some of these plantings. Results from these studies can provide comparisons of scale to address whether small-scale plantings can accurately predict the effects on birds and small mammals of extensively converting agricultural and CRP lands to biomass crop production.

Status/Accomplishments:

Studies to date have shown considerable variation in the density and species composition of birds and mammals that inhabit plantations. These differences are consequences of the variations in size, intensity of management, and landscape context of the various plantings. The numbers of individuals and species of birds found in hybrid poplar plantings were greater than in traditional row crop setting but less than in wildland forest and shrub habitats. The structural characteristics of the individual plantings and their location within the landscape also influenced the composition of bird communities and were more important indicators of community composition than changes in age (over 3 years) of the plantings. Small mammal communities on hybrid poplar plantings differed markedly from those in wooded and nonwooded wildland habitats, with the greatest differences between the plantings and wooded habitats. Distribution of species that inhabit hybrid poplar plantings indicates substantial interchange with adjacent grassland habitat but not with forest habitats. The abundance of small mammals on plantings also reflects the heterogeneity of the individual plantings. These results to date reflect the importance of landscape-level interactions between hybrid poplar plantings and the landscape and point to the need to further address how these woody crops can be best located within the landscape to increase habitat for bird and small mammal species.

Major Project Reports: See bibliography.

Summary Date: September 1995

Breeding Bird Use of Hybrid Poplar and Switchgrass Plantings

Directing Organization:

U.S. Department of Energy (DOE)
through the
Oak Ridge National Laboratory (ORNL)
P.O. Box 2008
Oak Ridge, TN 37831-6422

Project Manager: V.R. Tolbert

Telephone: (423) 574-7288

Contractor:

Scully Science Center
National Audubon Society
5500 S. Bay Avenue
Islip, NY 11751

Principal Investigators: J. Beyea, W. Hofman, and
J. Cook

Telephone: (516) 224-3730

Contract Number: 1BX-SL237

Contract Period: 4/92-9/96

Contract Funding (Source):

FY 1992: \$35,000 (DOE)
FY 1993: \$35,000 (DOE)
FY 1994: \$35,000 (DOE)
FY 1995: \$35,000 (DOE)

Objective:

Investigate the habitat value to migratory birds of research and large-scale biomass plantings of hybrid poplars and switchgrass.

Approach/Background:

Bird populations in hybrid poplar plantings in eastern Ontario, Oregon, and Washington, and switchgrass plantings in Iowa have been surveyed in the Spring during breeding season and during Fall migration to determine the use of these plantings compared with natural forests and grasslands.

Status/Accomplishments:

The hybrid poplar plantings support substantial bird populations during the breeding season. Species composition, however, differed substantially with plantation age. Younger plantations supported mostly edge and old-field species such as song sparrows, common yellowthroats, yellow warblers, and American goldfinches, which were common in the Ontario and western U.S. plantings. The older stands surveyed supported significant numbers of forest-interior birds,

including several species of flycatchers, thrushes, vireos, and warblers. The edge and old-field species tended to be absent from the interiors of the older plantations, but sometimes persisted on the plantation edges and in brushy habitat inclusions. The presence of forest-interior birds in these small plantings tended to be strongly influenced by landscape context. Older plantings that abutted natural woodlands had more forest-interior birds than those in more agricultural settings. Species diversity was augmented by complementary habitat inclusions that provided nesting habitat for several species that fed in the poplars. Densities in the poplar plantings peaked before canopy closure, when structural diversity and plant species diversity was highest. The same plantings supported far fewer birds in the Fall than nearby natural deciduous woodlands. In the Fall, most birds were not territorial and tended to congregate in the most attractive habitat patches.

Switchgrass plantings in Iowa provided significant habitat for several prairie specialist birds, most notably the sedge wren, dickcissel, and grasshopper sparrow. Bird use timing of these switchgrass plantings reflected the later seasonal growth patterns of this warm-season grass, and use by some species was influenced in two of the sampling periods by heavy rainfall and flooding.

Poplar and switchgrass plantings provided better breeding season habitat for native birds than did agricultural crops, but not as good as natural forest or prairie.

Major Project Reports: See bibliography.

Summary Date: September 1995

Cumulative Surface Water Effects

Directing Organization:

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through the
Oak Ridge National Laboratory (ORNL)
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Oak Ridge, TN 37831-6422

Project Manager: C.T. Hunsaker

Telephone: (423) 574-7365

Contractor:

Department of Agricultural and
Biological Engineering
Purdue University
1146 Agricultural Engineering Building
West Lafayette, IN 47907-1146

Principal Investigators: B.A. Engel and
M.J. Sears

Telephone: (317) 494-1198

Contract Number: 28X-SR254V

Contract Period: 6/94-12/95

Contract Funding (Source):

FY 1994: \$25,000 (DOE)

Objectives:

- Analyze the sensitivity of the Agricultural Non-Point Source pollution model (AGNPS) to changes in scales of data inputs and changes in grid size
- Model the impact on surface water quality when biomass is introduced into the landscape.

Approach/Background:

The preparation of data sets for use with AGNPS has included gathering information on soils (series and association units), land uses (field surveys, TM, and USGS LUDA), and DEMs (1:24,000 and 1:250,000). These data sets are being managed with the Geographical Analysis and Support System (GRASS) 4.1 GIS. Three watersheds (325, 6,239, and 11,294 ha) near West Lafayette, IN, were selected and proportioned at 100- and 200-m cell resolutions. Rainfall amounts and energy intensities, which are representative of 1-, 2-, 5-, 10-, 25-, 50-, and 100-year return period storms of 2- and 6-hour durations, were also calculated.

All possible permutations of these data inputs were defined for three variations on the land use data. These included Phase I: Current Conditions; Phase II: Economic Biomass (placed more frequently on soils on

which it is most productive); and Phase III: Water Quality Biomass (distributing biomass in the watershed as buffers around bodies of surface water). This resulted in the establishment of 2,352 model simulations to be completed. This was later reduced to 2,016, as a result of the model's inability to process the largest watershed at the finer resolution.

Status/Accomplishments:

We focused on preparing data inputs during 1994. In addition to previously mentioned data sets, inputs for other parameters required by the AGNPS-GRASS interface were developed. These include watershed boundaries, flow routing networks, soil textures and other properties, management practices, nutrient inputs, USLE C factors, and tillage passes.

In 1995, modeling efforts for Phases I and II were completed. Phase III is in progress. Results analysis is partially completed, and results are still preliminary.

Major Project Reports: See bibliography.

Summary Date: September 1995

Development of *in vitro* Culture Systems for Switchgrass (*Panicum virgatum*)

Directing Organization:

U. S. Department of Energy (DOE)
through the
Oak Ridge National Laboratory (ORNL)
P.O. Box 2008
Oak Ridge, TN 37831-6422

Project Manager: S.B. McLaughlin

Telephone: (423) 574-7358

Contractor:

Agricultural Experiment Station
University of Tennessee
Knoxville, TN 37901-1071

Principal Investigator: B.V. Conger

Telephone: (423) 974-8833

Contract Number: 11X-SL129C

Contract Period: 7/92-6/97

Contract Funding (Source):

FY 1992: \$47,000 (DOE)
FY 1993: \$53,000 (DOE)
FY 1994: \$52,000 (DOE)
FY 1995: \$60,000 (DOE)

Objective:

Develop efficient and repeatable regeneration systems from cell and tissue cultures of switchgrass (*Panicum virgatum*).

Approach/Background:

Research efforts to improve biomass production of switchgrass through breeding, genetics, and physiology should logically include the development of systems that can be used in the potential application of biotechnology. Most, if not all, these applications require whole plants to be regenerated from cells or tissues cultured *in vitro*.

Status/Accomplishments:

Experiments were conducted with Alamo to test the effect of regeneration cycle on regeneration frequency. Results showed that regeneration increased more than fourfold between the first and second cycles. There was no further increase with additional culture cycles.

Mature caryopses, seedling segments from greenhouse plants, and seedling segments from regenerated plantlets were used as explants to initiate cultures of the cultivars Kanlow, Cave-in-Rock, and Trailblazer.

Regeneration capacity of the upland types was lower than that of Kanlow regardless of explant and medium composition.

Much emphasis during the past 2 years was placed on node cultures. There were two objectives: (1) to develop a system for micropropagation in which shoots or plantlets are produced directly from the explant and (2) to produce inflorescences from the top node. Nodal segments were obtained from green house grown plants of Alamo in the four- to six-node state, surface sterilized, split longitudinally along the sheath edge, and plated with the cut edge in contact with MS medium containing 22.5 M 2,4-D and 12.5 M BAP. Shoots emerged at 1 week culture. Results indicated that under optimum conditions, approximately 500 plants could be produced from one parent plant in 12 weeks. The uppermost node contains the shoot apical meristem. Splitting this node and plating onto medium resulted in the production of inflorescences to a mature stage. Inflorescences could be produced from both halves of the node if a portion of the inflorescence was included in each half. Inflorescences developed on medium without BAP were elongated and possessed between 50 and 200 florets. If BAP (5.0 to 25.0 M) was included in the medium, the inflorescences were more compact and possessed between 200 and 700 florets. Our procedures for both shoot and inflorescence production from nodal segments is reliable and highly reproducible. Also, the responses do not appear to be as cultivar dependent as other *in vitro* procedures.

Major Project Reports: See bibliography.

Summary Date: September 1995

Effects of Herbaceous and Woody Energy Crops on Uptake, Release and Off-Site Movement of Nutrients and Pesticides

Directing Organization:

U.S. Department of Energy (DOE)
through the
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P.O. Box 2008
Oak Ridge, TN 37831-6422

Project Manager: V.R. Tolbert

Telephone: (423) 574-7377

Contractor:

Forestry Sciences Laboratory
USDA Forest Service
5985 Highway K
Rhineland, WI 54501

Natural Resources Research Institute
University of Minnesota
5013 Miller Trunk Highway
Duluth, MN 55811

Principal Investigators: J.G. Isebrands,
W.E. Berguson, K.N. Brooks, and D.F. Grigal

Telephone: (218) 720-4296 (W.E. Berguson)

Contract Number: DE-AI05-95OR22368

Contract Period: 12/94-9/96

Contract Funding (Source):
FY 1995: \$111,600 (DOE)

Objective:

Investigate the effect of hybrid poplar plantations and switchgrass on water quality and compare these effects to an agronomic crop (wheat) managed under a typical fertilizer/herbicide regime.

Approach/Background:

A potential benefit associated with changing land use from traditional agriculture to hybrid poplar or switchgrass is water quality enhancement. Inputs of chemicals in managing most agronomic crops are considerably greater than those required for producing hybrid poplar or switchgrass. The purpose of this project is to test the hypothesis that water quality is enhanced under energy crop management compared to agronomic crops, in our case, wheat. This project selects sites and establishes crops, studies groundwater quality and nutrient cycling, and estimates the water budget. Plans are to establish the soil and groundwater monitoring system in the Spring and Summer of 1996

and monitor water quality and quantity during the summer to establish background levels. Water will be sampled using a combination of zero-tension and ceramic cup samplers at three soil depths. A site will be prepared during the Summer and Fall of 1995 and the crop will be planted in the Spring of 1997.

Status/Accomplishments:

A 13-acre site located in Red Lake County, MN, has been selected for this study. Through the cooperation of a local farmer involved in other hybrid poplar projects in the area, the site was summer-fallowed before the project started. The site has been plowed and disked several times to maintain a weed-free condition during the 1995 growing season. Staff from the U.S. Geological Survey began a series of test borings to determine the depth of the water table and direction of groundwater flow. These borings indicated the presence of a flow-restricting layer at an average depth of 8 feet. Because of this, we changed the sampling design to concentrate water sample collection within the top 8 feet of soil. We will not establish a series of groundwater sampling tubes because water flowing downward through the soil profile will be intercepted by the impeding layer and flow laterally to the north of the site. Discussions are taking place with other researchers in the state to determine the best design for constructing the zero-tension and porous cup lysimeters. These samplers will be constructed during the Winter and installed in the Spring of 1996.

Major Project Reports: None.

Summary Date: September 1995

Energy Crop Data and Information Management

Directing Organization:

U.S. Department of Energy (DOE)
through the
Oak Ridge National Laboratory (ORNL)
P.O. Box 2008
Oak Ridge, TN 37831-6422

Project Manager: J.H. Cushman

Telephone: (423) 574-7818

Contractor:

Biofuels Feedstock Development Program (BFDP)
Oak Ridge National Laboratory
Oak Ridge, TN 37831-6422

Principal Investigator: A.R. Ehrenshaft

Telephone: (423) 576-5132

Contract Number: N/A

Contract Period: N/A

Contract Funding (Source):
FY 1995: \$280,400 (DOE)

Objective:

Develop products and services to meet the information needs of a diverse community of customers and stakeholders that includes researchers, policymakers, entrepreneurs, utility companies, land owners, and the general public.

Approach/Background:

As the research efforts funded by BFDP have matured and expanded into new areas, creating, maintaining, and keeping information and data accessible have become increasingly important. Products and services to anticipate and respond to the increased demands for these data and information are needed. All other BFDP tasks contain strong information and outreach elements that are funded directly by these tasks. These activities are done by the task leaders and subcontractors and include presentations, conference papers, posters, white papers, journal articles, and numerous personal communications. These products, for the most part, are aimed at the research community and technically inclined policymakers. This task makes the materials available to a wider audience.

This BFDP task is responsible for developing and distributing newsletters, fact sheets, and visuals (slides and view graphs) and for responding to requests for information about energy crops. Increased emphasis is being placed on defining the audience for each information product. BFDP will continue to tap into

the power of the Internet to provide public access to information from DOE and ORNL.

Status/Accomplishments:

During FY 1995, work concentrated on tasks to support the Biofuels Systems Division's (BSD's) Strategic Goal 4 to establish an effective external and internal communications, education, and coordination effort. The Biofuels Information Network, BSD's on-ramp to the Internet, was expanded and enhanced. Two BSD and six BFDP reports and two handouts (precursors to fact sheets) were converted for electronic dissemination. A bibliography of program-sponsored research was published during this period and subsequently converted for on-line access.

Two issues of *The Energy Crops Forum*, the BFDP newsletter whose purpose is to facilitate communications among a community of researchers, policymakers, and potential users and producers of energy crops, were published. The Biomass Interest Group database, BFDP's contacts file, was shared in various formats with about five other organizations to facilitate their information dissemination. Technical databases that contain the results of the energy crop research efforts are in place. The herbaceous energy crops database was updated during FY 1995. We continued to maintain BIOBIB, a bibliographic database for program-sponsored publications, presentations, and related materials. Information is presently disseminated as requested as ORNL staff respond to inquiries from the public, media, government officials, universities, and other research institutions. Staff members were encouraged to maintain a log to track these requests. BFDP staff helped establish BSD's Communications Working Group and provided support for the Southern Biofuels Roundtable and the Environmental Effects of Energy Crop Production conference.

Major Project Reports: See bibliography.

Summary Date: September 1995

The Environmental Effects of Biomass Crop Development Conference

Directing Organization:

U.S. Department of Energy (DOE)
through the
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Oak Ridge, TN 37831-6422

Project Manager: J.H. Cushman

Telephone: (423) 574-7818

Contractor:

Biofuels Feedstock Development Program (BFPD)
Oak Ridge National Laboratory
Oak Ridge, TN 37831-6422

Principal Investigator: V.R. Tolbert

Telephone: (423) 574-7288

Contract Number: N/A

Contract Period: 10/95-9/96

Contract Funding (Source):

FY 1995: \$25,000 (DOE)
FY 1995: \$ 2,000 (AF&PA)
FY 1995: \$10,000 (U.S. EPA)

Objective:

Provide a forum at which to present research results and needs of the environmental effects of biomass crop production.

Approach/Background:

The conference was cosponsored by BFPD, the U.S. Environmental Protection Agency Office of Global Climate Change, and the American Forest and Paper Association. A framework within which to address biomass crop development using a context of agricultural, forestry, and industrial sustainability was established.

Status/Accomplishments:

The conference provided the opportunity for participants to exchange information and ideas. Questions about the environmental benefits of biomass crop production were asked and answered. Results of several site-specific studies showed that woody and herbaceous crops increase carbon sequestration when land is converted from traditional row crops to biomass crops because of their extensive rooting systems and annual turnover of fine roothairs. These rooting systems also require lower nutrient input, provide site stabilization, and reduce erosion compared with

traditional row crops. Biomass crops were easily incorporated into the landscape to provide buffer strips along waterways and drainage areas and to serve as reclamation and stabilization species for highly erodible lands. Several studies of herbaceous and woody crops show that biomass crops can increase habitat for bird species. Regional studies in the Tennessee Valley have identified several areas with potential for producing these biomass crops.

Conference speakers addressed a number of research areas, including genetic development of crops with specific traits to meet regional needs, where questions still need to be answered to ensure successful development and deployment of biomass crops. These questions include measures to increase the environmental benefits of biomass crop production while meeting the economic needs of individual crop producers, local agricultural communities, industrial consumers at both local and regional scales.

Major Project Reports: None.

Summary Date: September 1995

Evaluation of Genetic Selection Criteria for *Populus* Clones

Directing Organization:

U.S. Department of Energy (DOE)
through the
Oak Ridge National Laboratory (ORNL)
P.O. Box 2008
Oak Ridge, TN 37831-6422

Project Manager: G.A. Tuskan

Telephone: (423) 576-8141

Contractor:

North Central Forest Experiment Station
USDA Forest Service
Rhineland, WI 54501

Principal Investigator: J.G. Isebrands

Telephone: (715) 362-7474

Contract Number: DE-AI05-940R22197

Contract Period: 2/94-3/99

Contract Funding (Source):

FY 1994: \$138,850 (DOE)
FY 1995: \$156,300 (DOE)

Objective:

Evaluate quantitative genetic selection criteria for *Populus* clones for use in biomass plantations as a biofuels feedstock.

Approach/Background:

Research studies performed under this interagency agreement are part of an interdisciplinary program jointly funded by DOE and the USDA Forest Service. Scientific information is being developed to test physiological selection criteria for *Populus* clones grown under short rotation for use in selecting and breeding biofuels feedstock. Process models are used to help select clones and understand which traits are most important for early selection.

Status/Accomplishments:

Studies were conducted to determine the genotypic and phenotypic variances among important traits in black cottonwood (*Populus trichocarpa*) collections from British Columbia and Idaho. Tree height, phenology, leaf morphology, and leaf diseases exhibited high heritability. Relation of traits varied between collections, suggesting that selection strategies for disease resistance need to be evaluated for each population. Leaf size, number, and the number of sylleptic branches show promise for use in early selection for increasing biomass productivity.

An ecophysiological process model, ECOPHYS, was used to evaluate sampling schemes for estimating whole tree photosynthesis during the season in *Populus* clones. Clone growth was simulated under varying weather conditions and leaf display patterns over the course of the entire growing season. Whole tree photosynthesis was best estimated by sampling schemes that used physiologically based approaches when compared to random or stratified random approaches for all combinations of clone type, weather condition, and leaf orientation. A process model that uses ECOPHYS is also being used to assess the environmental impact of planting short-rotation poplars in a region with respect to soil erosion and water runoff.

Major Project Reports: See bibliography.

Summary Date: September 1995

Farm-Level Issue Analysis

Directing Organization:

U.S. Department of Energy (DOE)
through the
Oak Ridge National Laboratory (ORNL)
P.O. Box 2008
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Project Manager: M.E. Downing

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Contractor:

American Energy Crop Association (AECA)
1018 North Bombart
St. Louis, MO 63119

Principal Investigators: D. Hines

Telephone: (314) 962-4307

Contract Number: 87X-SS339V

Contract Period: 9/94-8/95

Contract Funding (Source):

FY 1994: \$74,000 (DOE)
FY 1995: \$24,000 (DOE)

Objectives:

- Develop a framework for understanding the ways energy crops would be adopted by farmers
- Develop a survey to characterize farmer knowledge base and understanding of energy crops
- Define efforts and mechanisms by which energy crop information can be made available to a wide audience.

Approach/Background:

The principal investigator established contacts with members of the media who report on and investigate agricultural issues of concern to farmers.

Status/Accomplishments:

AECA was an exhibitor at a Future Farmers of America Career show and a sponsor of the National Association of Farm Broadcasters (NAFB) meeting. Fourteen interviews were conducted with farm broadcasters who represented more than 200 station affiliations, covering virtually the entire farm listening audience of the United States. Similar activities were undertaken throughout the period. A media list of more than 200 farm writers and broadcasters was developed and used as part of the distribution list for *The Bottom Line*, a newsletter published periodically during this period. Several articles about energy crops in the

United States were placed in publications read by farmers.

A survey was developed and refined. It has been published in the *Mid-America Farmer Grower* magazine, which has 12,000 paid subscribers. Several meetings were conducted in Illinois and Missouri to bring together agribusinesses, policy-makers, farmers, researchers, and businesses.

Major Project Reports: None.

Summary Date: September 1995

Genetic Improvement and Evaluation of Black Cottonwood for Short-Rotation Biomass Production

Directing Organization:

U.S. Department of Energy (DOE)
through the
Oak Ridge National Laboratory (ORNL)
P.O. Box 2008
Oak Ridge, TN 37831-6422

Project Manager: G.A. Tuskan

Telephone: (423) 576-8141

Contractors:

University of Washington
Seattle, WA 98195

Western Washington Research and
Extension Center
Puyallup, WA 98371

Principal Investigators: R.F. Stettler,
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H.D. Bradshaw, Jr.

Telephone: (206) 543-2723

Contract Number: 41XSN799C

Contract Period: 5/94-4/99

Contract Funding (Source):

FY 1994: \$200,000 (DOE)
FY 1995: \$200,000 (DOE)

Objectives:

- Genetically improve black cottonwood (*Populus trichocarpa*) for biomass production
- Define critical components of productivity and how they can be manipulated genetically and environmentally
- Encourage industrial poplar culture in the Northwest.

Approach/Background:

This project provides information on cultural requirements and productivity of black cottonwood hybrids when grown under short-rotation intensive culture.

Status/Accomplishments:

More than 8,000 ha of the hybrid material developed in the program is now being grown by forestry industry and farmland owners in Oregon, Washington, and British Columbia. More than 2,000 selected clones are under testing in 42 field trials located within the region.

The quantitative trait loci (QTL) mapping effort documented definite interaction between QTL expression for growth in stem basal area and site/environment. The three site/environments in the study were located at Puyallup, WA, Clatskanie, OR, and Boardman, OR. Also revealed in the year's study was allelic variation in QTLs in two families with different male *Populus deltoides* grandparents. A Poplar Molecular Genetics Cooperative was formed to increase understanding of poplar genetics and to use this information to aid in poplar breeding and selection.

Three new plantations were installed in 1994. One evaluates clone/spacing interactions. The test contains three clones and three spacings from 1.2 m to 3.7 m. Another is a Phase I clone trial with new materials, and the third evaluates the use of biosolids with method of irrigation (drip versus minisprinklers). Results of clone testing showed poor correlation between height at age 1 and production of bole volume at age 3, caused in part by the slowdown in growth of TxM hybrids at age 3 versus the accelerating growth of TxN clones at that age. Also evident after 3 years was the significantly superior production of diploid F1 hybrids compared to related triploids.

Major Project Reports: See bibliography.

Summary Date: September 1995

Genetic Variation among Switchgrasses for Agronomic Traits, Forage Quality, and Biomass Fuel Production

Directing Organization:

U.S. Department of Energy (DOE)
through the
Oak Ridge National Laboratory (ORNL)
P.O. Box 2008
Oak Ridge, TN 37831-6422

Project Manager: S.B. McLaughlin

Telephone: (423) 574-7358

Contractor:

Agricultural Research Service
U.S. Department of Agriculture
Lincoln, NE 68583-0910

Principal Investigator: K.P. Vogel

Telephone: (402) 472-1564

Contract Number: DE-AI05-900R21954

Contract Period: 9/90-9/97

Contract Funding (Source):

FY 1990	\$ 17,600	(DOE)
FY 1991	\$ 44,000	(DOE)
FY 1992	\$ 44,000	(DOE)
FY 1993	\$ 0	
FY 1994	\$115,000	(DOE)
FY 1995	\$115,000	(DOE)

Objective:

Develop improved genetic information and strains, and associated agronomic technology to develop switchgrass into a biomass fuel crop for the midwestern states.

Approach and Background:

The first phase of this research determined the genetic variation among switchgrasses for biomass fuel production traits and their stability over environments. In the second phase, research is being conducted to:

- Develop molecular genetic markers to classify switchgrasses, germplasm, and mapping genes that control specific traits
- Determine the feasibility of producing F1 switchgrass hybrid cultivars
- Determine the optimum rate of nitrogen fertilization and stage of maturity that will result in the largest economical yields of extractable ethanol per acre in the midwestern states
- Determine the effectiveness of new herbicides in

aiding switchgrass establishment

- Determine whether vesicular-arbuscular micorrhizae improve the establishment of switchgrass and the efficiency of nutrient utilization.

Status and Accomplishments:

Phase I successfully demonstrated significant differences among elite switchgrass strains for biomass production in the midwestern states. Despite large genotype x environment interaction effects, some strains consistently produced large biomass yields. Assuming a conversion efficiency of 75%, the best strains can produce more than 5,000 L/ha (500 gal/acre) of ethanol. This research provided documentation for releasing the cultivar "Shawnee" to seed growers in 1995. An associated study evaluated germplasm collected from remnant prairies and demonstrated significant genetic variation among accessions. Some of the accessions will be valuable in switchgrass breeding programs.

Current research demonstrates two distinct types of switchgrasses based on chloroplast RFLPs (a type of molecular genetics marker), which are directly associated with the lowland and upland ecotypes. Nuclear DNA content of most available switchgrass germplasms and cultivars was determined using flow cytometry. Results indicate that tetraploid strains have DNA contents of approximately 3 pg/nuclei, whereas previously reported "hexaploid" strains contain 6 pg/nuclei. A cytogenetic investigation demonstrated that strains with 6 pg DNA/nuclei are octaploids.

The research on developing F1 hybrids, new herbicides, and vesicular-arbuscular micorrhizae were established and are in progress.

Major Project Reports: See bibliography.

Summary date: September 1995

Harvesting Initiatives

Directing Organization:

U.S. Department of Energy (DOE)
through the
Oak Ridge National Laboratory (ORNL)
P.O. Box 2008
Oak Ridge, TN 37831-6422

Project Manager: L.L. Wright

Telephone: (423) 574-7378

Contractor(s): N/A

Principal Investigator: R.D. Perlack

Telephone: (423) 574-5186

Funding (Source):

FY 1995: \$25,000 (DOE)

Objective:

Initiate a coordinated and cooperative harvesting and handling systems research agenda that involves the forest products industry, equipment manufacturers, the U.S. Department of Agriculture (USDA) Forest Service, electric utilities through the Electric Power Research Institute (EPRI), DOE, and its subcontractor, ORNL. Specific goals are to:

- Review harvesting/handling systems, including obstacles to developing specialized equipment
- Identify and rank forest product industry and other user needs
- Outline a harvesting and handling (mechanization) systems research agenda
- Propose and initiate a means or action plan to carry out the agenda in full cooperation with all interested partners.

Approach/Background:

To realize the potential and to make short rotation woody crop (SRWC) feedstocks more competitive in the marketplace, the costs of harvesting and handling systems must be reduced. In a mutually beneficial and collaborative fashion, the USDA Forest Service, ORNL, and EPRI have established an SRWC Operations Working Group to consider the efficient development of practices and equipment to culture, harvest, and handle large-scale woody biomass plantations.

Status/Accomplishments:

The major accomplishment of this initiative was the organization of an SRWC Operations Steering

Committee meeting in cooperation with the USDA Forest Service (Southern Research Station, Auburn University, AL) and EPRI (Palo Alto, CA). The committee provides the basis for promoting collaborative action and research and facilitating funding support for equipment and systems development. A major workshop is planned for FY 1996. With funding from EPRI, ORNL will also work with the University of California (Davis) to develop a status report on SRWC operations technologies and systems.

Major Project Reports: See bibliography.

Summary Date: September 1995

Minnesota Wood Energy Scale-Up Project

Directing Organization:

U.S. Department of Energy (DOE)
through the
Oak Ridge National Laboratory (ORNL)
P.O. Box 2008
Oak Ridge, TN 37831-6422

Project Manager: M.E. Downing

Telephone: (423) 576-8140

Contractor:

WesMin Resource Conservation
& Development Council (RC&D)
910 Highway 29 North, Suite 103
Alexandria, MN 56308

Principal Investigator: G. Larson

Telephone: (612) 763-4733

Contract Number: 15X-SP814V

Contract Period: 1/94-12/97

Contract Funding (Source):

FY 1994: \$ 97,000 (DOE)
FY 1995: \$100,000 (DOE)

Objectives:

- Plant 2,000 acres of hybrid poplar on agricultural lands with varying soils and adjacent land uses and types
- Develop a vendor system to plant, tend, and monitor hybrid poplar plantations
- Determine potential environmental effects of hybrid poplar on small mammals and birds
- Gather specific economic, environmental, and hybrid poplar production data
- Offer acceptable financial returns to landowners and farmers with alternative crops
- Take advantage of the USDA's Conservation Reserve Program 5-year extension opportunity if the land is planted to hardwood trees.

Approach/Background:

A multidisciplinary team, which includes representatives from the Minnesota Department of Natural Resources Division of Forestry, the USDA Forest Service, the USDA Natural Resources Conservation Service, Natural Resources Research Institute, the University of Minnesota, Duluth (Biology Department), and RC&D was organized to direct and manage project implementation. Contracts were placed with vendors to plant 2,000 acres of hybrid poplar within a

50-mile radius of Alexandria, MN, and to maintain the plantations. Weekly plantation visits to monitor plantation condition and growth were conducted.

Status/Accomplishments:

During the first phase, primary site preparation (tillage) was begun. Hybrid poplar cuttings (10 hardwood cuttings/sticks) were planted at a rate of 681 per acre during the Spring of 1994. Throughout the 1994 growing season, vendors completed weed control operations. Thirteen sites were planted, the largest planting being 160 acres. Several failed because of very wet conditions that saturated the soil and prohibited maintenance. Four hundred fifty acres were replanted during the Spring of 1995. Tree growth to date, after two growing seasons, approaches 15 feet on several plantations.

The second phase expanded the planting project by 1,000 acres. Site preparation began in 1994, and planting was completed during the Spring of 1995. All Phase 2 acres were hand planted by local and professional planting crews. The largest plantation is 300 acres. Vendors are cultivating, applying herbicides to, and monitoring the five plantations. Tree growth on one plantation, after one growing season, is nearly 8 feet.

Approximately 400 acres will be replanted in 1996 because of extreme weather conditions during the Summer of 1995. Nearly all acreage will be treated with the herbicide Oust during the Fall of 1995 to help control weed growth during the 1996 growing season.

Major Reports: None.

Summary Date: September 1995

Optimal Establishment and Cultural Practices for Switchgrass as an Energy Crop in the Southeastern United States

Directing Organization:

U.S. Department of Energy (DOE)
through the
Oak Ridge National Laboratory (ORNL)
P.O. Box 2008
Oak Ridge, TN 37831-6422

Project Manager: S.B. McLaughlin

Telephone: (423) 574-7358

sandy loam soil in south central Alabama has provided an average yield of 25.8 Mg/ha. However, there has been a general decreasing trend in these yields, and production in commercial scale fields is expected to be about 30% lower.

Major Project Reports: See bibliography.

Summary Date: September 1995

Contractor:

Department of Agronomy and Soils
Auburn University
Auburn, AL 36849-5412

Principal Investigator: D.I. Bransby

Telephone: (334) 844-4100

Contract Number: 38X-SL227C

Contract Period: 6/92-5/96

Contract Funding (source):

FY 1992: \$ 72,250 (DOE)
FY 1993: \$ 85,000 (DOE)
FY 1994: \$ 85,000 (DOE)
FY 1995: \$102,000 (DOE)

Objective:

Develop optimal establishment and cultural practices for switchgrass as an energy crop in the southeastern United States.

Approach/Background:

Switchgrass will be evaluated as an energy crop in small plot studies to determine optimal methods of weed control at establishment; evaluate effects of row spacing, subsoiling, fertilization and legume companion crops for increasing yield; and identify and test alternative varieties of switchgrass across several locations.

Status/Accomplishments:

All plot studies were seeded and good stands were obtained. Alamo continues to be the best variety at all locations in Alabama. A wide row spacing (0.8 m) gave higher yields than the narrow (0.2 m) row spacing. Yield increased with nitrogen fertilization up to 200 kg nitrogen/ha, but this response was greater at the wide row spacing. Increasing row spacing from 0.2 m to 0.8m and nitrogen fertilization from 112 kg/ha to 224 kg/ha increased yield by 68%. During the past 5 years, yields from Alamo switchgrass in plots on a

Poplar Molecular Genetics Cooperative

Directing Organization:

U.S. Department of Energy (DOE)
through the
Oak Ridge National Laboratory (ORNL)
P.O. Box 2008
Oak Ridge, TN 37831-6422

Project Manager: G.A. Tuskan

Telephone: (423) 576-6830

Contractor:

University of Washington
Seattle WA 98195

Principal Investigator: H.D. Bradshaw, Jr.

Telephone: (206) 616-1796

Contract Number: RFP ST806-19

Contract Period: 4/95-3/96

Contract Funding (Source):

FY 1995: \$58,000 (DOE)

Objectives:

- Use molecular markers and genome maps to pinpoint quantitative trait loci controlling tree growth, wood properties, stress tolerance, and disease resistance to increase understanding of the molecular genetic mechanisms that cause variation in productivity and quality traits in hybrid poplar
- Use research results to accelerate progress in poplar breeding.

Approach/Background:

The key to sustained genetic improvement in *Populus* is a detailed understanding of the genetic architecture of important phenotypic traits such as stem volume, wood quality, and disease resistance. Such an understanding will accelerate progress in breeding by providing improved methods to identify superior clones for immediate commercial use and parents for the next generation of hybrids.

Status/Accomplishments:

Ten private forest products companies have joined DOE in supporting the PMGC financially, and additional support comes from the USDA Forest Service and British Columbia Ministry of Forests. In the first few months, more than 120 interspecific hybrid crosses were attempted, and more than 2,000 new hybrid poplar clones were produced. Parental species were collected over a wide latitudinal range and across moisture and climatic gradients to provide genetically

informative hybrids suited to a wide range of growing conditions.

Major Project Reports: See bibliography.

Summary Date: September 1995

***Populus* Crop Development in the Southeast United States**

Directing Organization:

U.S. Department of Energy (DOE)
through the
Oak Ridge National Laboratory (ORNL)
P.O. Box 2008
Oak Ridge, TN 37831-6422
transferred to
JAYCOR
1608 Spring Hill Road
Vienna, VA 22182-2270
and
Southern Research Station
USDA Forest Service
P.O. Box 2680
Asheville, NC 28802

Project Manager: G.A. Tuskan

Telephone: (423) 576-8141

Contractor:

Forest and Wildlife Research Center
Mississippi State University
Mississippi State, MS 39762

Principal Investigators: S.B. Land, Jr., M. Stine,
and D.L. Rockwood

Telephone: (601) 325-2946

Contract Numbers:

12DB-99230 (JAYCOR) and
DE-AI05-95OR22408 (USDA Forest Service)

Contract Period:

2/95-6/96 (JAYCOR)
7/95-8/99 (USDA Forest Service)

Contract Funding(Source):

FY 1995: \$106,615 (DOE/JAYCOR)
FY 1995: \$105,049 (DOE/USDA Forest Service)

Objective:

Develop improved genetic varieties (clones) of eastern cottonwood (*Populus deltoides* Bartr.) and its hybrids for use in energy and fiber crops throughout the southeastern United States.

Approach/Background:

Research will identify appropriate sources (provenances) for various parts of the region, investigate methods for stimulating early flowering, identify physiological reasons for broad adaptability, and determine whether quantitative trait loci (QTL) can be identified for yield traits.

Open-pollinated seeds from natural stands in three of six subregions in the southeastern United States, and cuttings from tested clones in the other three subregions, will be collected during the first 2 years. Crosses among the tested clones will occur during the first 3 years to produce pedigreed material (control-pollinated seeds) for second-generation genetic improvement and QTL analyses. Field trials with cuttings from the open-pollinated and controlled pollinated seedlings will be established on river-bottom and upland sites in all six subregions during years 3-6. Clone selection in these tests will be based on rapid juvenile growth rate, *Melampsora* leaf rust resistance, and high wood specific gravity.

Status/Accomplishments:

Cuttings from 142 tested clones were planted in a nursery and breeding orchard at Stoneville, MS. Fifteen forest industries have agreed to help locate natural stands and provide flowers/cuttings or test sites. Searches for stands are now under way. Greenhouse facilities at Mississippi State University are being renovated to provide a temperature-controlled room for controlled pollinations. DNA has been prepared from 37 clones at Louisiana State University to test markers for QTL analyses.

Major Project Reports: None.

Summary Date: September 1995

Productivity Research of Switchgrass (*Panicum virgatum*) as a Biofuels Crop

Directing Organization:

U.S. Department of Energy (DOE)
through the
Oak Ridge National Laboratory (ORNL)
Oak Ridge, TN 37831-6422

Project Manager: S.B. McLaughlin

Telephone: (423) 574-7358

Contractor:

Oak Ridge National Laboratory (ORNL)
P.O. Box 2008
Oak Ridge, TN 37831-6422

Principal Investigators: S.D. Wullschleger,
L.E. Gunter, and G.A. Tuskan

Telephone: (423) 574-7839

Contract Number: N/A

Contract Period: N/A

Contract Funding (Source):

FY 1992: \$50,000 (DOE/ORNL)
FY 1993: \$90,000 (DOE/ORNL)
FY 1994: \$90,000 (DOE/ORNL)
FY 1995: \$96,000 (DOE/ORNL)

Objective:

Detect physiological and molecular indicators of genetic diversity, which relate variation in specific traits to biomass productivity, in the herbaceous energy crop switchgrass.

Approach/Background:

A combination of techniques is used to study the interface between switchgrass physiology and genetics. Field studies characterize process-level rates of photosynthesis, respiration, and water-use efficiency, and DNA fingerprinting helps establish genetic relatedness among released and experimental lines of switchgrass.

Status/Accomplishments:

Physiological studies examine the extent of genetic diversity in switchgrass. Photosynthesis, respiration, and whole-plant water loss vary among released and experimental lines, although rates of carbon and water exchange are not robust indicators of above-ground biomass productivity. Below-ground processes such as carbon allocation, root turnover, and nutrient cycling, however, is viewed as important contributors to high yield in switchgrass.

Polymorphisms among molecular markers produced from the amplification of genomic DNA (RAPD-PCR) are also used to assess genetic differences within and among ecotypes of switchgrass. This method quantifies genetic relatedness and thus provides a rapid evaluation of germplasm within switchgrass breeding programs. Relatively few markers are needed to distinguish individual genotypes, and the ability to detect these differences seems high.

Genetic variability in switchgrass revealed via physiological and molecular techniques should enable researchers to screen for traits of interest to the biofuels industry. These technologies may enhance biomass production in the United States by identifying switchgrass cultivars better adapted to specific climatic and edaphic conditions. The novel application of molecular techniques could also provide a powerful tool for identifying and introducing new cultivars into plant breeding programs.

Major Project Reports: See bibliography.

Summary Date: September 1995

Regional-Scale Integrated Modeling System to Evaluate the Potential Cost and Supply of Biomass from Energy Crops

Directing Organization:

U.S. Department of Energy (DOE)
through the

Oak Ridge National Laboratory (ORNL)
P.O. Box 2008
Oak Ridge TN 37922-6422

Project Manager: J.H. Cushman

Telephone: (432) 574-7818

Contractor:

Oak Ridge National Laboratory (ORNL)
P.O. Box 2008
Oak Ridge TN 37922-6335

Principal Investigator: R.L. Graham

Telephone: (423) 576-7756

Contract Number: N/A

Contract period: 10/93-10/96

Contract Funding (Source):

FY 1993: \$226,000

FY 1994: \$450,000

FY 1995: \$110,000

Objective:

Develop a Geographic Information System based modeling system designed to provide geographically specific information on the probable cost and supply of biomass feedstock from energy crops. The system is designed to evaluate individual U.S. states.

Approach/Background:

The system incorporates land use and road network information, with transportation, economic, and environmental models to predict where energy crops would be grown, the cost of supplying biomass from energy crops to specific locations, and the environmental consequences of providing that supply. As most information regarding energy crops has a high degree of uncertainty, the modeling system has a modular design to permit quick updating and flexibility. This flexibility is also essential for using the model to evaluate various economic assumptions or the effects of uncertainty on the underlying input data or algorithms.

The system strives to capture the geographic variation in the factors that will determine biomass availability (supply and cost). Producing economically competitive bioenergy, be it electric power or liquid fuels, is strongly dependent on the availability of low-cost feedstock. That availability will have spatial variation,

so it is critical to evaluating the real potential of bioenergy for a region.

The system can provide guidance for technology development by identifying the optimal size for a conversion facility (ethanol or power plant); the model results can define the relationships between conversion facility feedstock demand, feedstock cost, and availability of locations that can meet specified conversion facility demands. Locations with the greatest commercial potential for bioenergy can also be identified by the system; that is, locations where energy crop production could be economically competitive over large acreages at low farmgate prices.

Status/Accomplishments:

To date, system model parameters have been developed for 11 states (Alabama, Florida, Georgia, Iowa, Minnesota, Missouri, Nebraska, North Dakota, South Carolina, South Dakota, and Tennessee). The basic algorithms and code for the model have been developed and are now being tested. The modeling system has been presented at an international meeting. Documentation of model code and algorithms and analysis of baseline runs for the 11 states will be complete by the end of September 1996.

Major Project Reports: See bibliography.

Summary Date: October 1995

Regional Testing of *Populus* Clones

Directing Organization:

U.S. Department of Energy (DOE)
through the
Oak Ridge National Laboratory (ORNL)
P.O. Box 2008
Oak Ridge, TN 37831-6422

Project Manager: G.A. Tuskan

Telephone: (423) 576-8141

Contractor:

North Central Forest Experiment Station (NCFES)
USDA Forest Service
1993 Folwell Avenue
St. Paul, MN 55108

Principal Investigator: D.E. Riemenschneider

Telephone: (715) 362-1115

Contract Number: DE-AI05-950R22437

Contract Period: 8/95-8/99

Contract Funding (Source):
FY 1995: \$100,000 (DOE)

Objective:

Extend previous poplar breeding and selection in the north central United States by implementing a regional testing system with four test locations in Minnesota, Iowa, Wisconsin, and Michigan. Multiple traits will be evaluated simultaneously and selection indices developed to improve height, caliper, and resistance to biotic and abiotic stresses. Testing will focus on Eastern cottonwood (*Populus deltoides*), which has potential as a biofuels crop *per se* and has potential value as a parent in interspecific hybridizations. Eastern cottonwood has been selected as the primary species for woody biofuels development in the north central United States because of its relative resistance to *Septoria* canker, which limits deployment of many poplar hybrids in the region.

Status/Accomplishments:

Administrative arrangements were made to support all cooperators in the regional field test through federal assistance agreements with NCFES. Agreements are now in force between NCFES and Pope County Soil and Water Conservation District, the University of Minnesota, Iowa State University, the University of Wisconsin, and Michigan State University.

Clones were selected from nurseries at Iowa State University and the University of Minnesota (Grand Rapids, MN) based on age, 2-year growth, and

resistance to leaf diseases. We selected 43 clones of *P. deltoides*, 10 clones of *P. deltoides* x *P. maximowiczii* F₁ hybrids, three clones of *P. deltoides* x *P. nigra* F₁ hybrids, one clone of *P. nigra* x *P. maximowiczii*, and four clones of aspen hybrids. Control clones in the experiment include NM-6 (one of the most promising new commercial clones) and DN-34 (currently the most widely planted commercial clone in the north-eastern United States).

Rooted 1-year-old plants were lifted from nurseries in late April or early May 1995. The current terminal shoot was pruned to approximately 10 cm and plants were held in cold storage until delivery to the planting sites during the week of May 15. Tests were established at Westport, MN; Ames, IA; Madison, WI; and East Lansing, MI, according to plan. In each case, the planting design was 10 randomized incomplete blocks with two tree plots. All plantings were inspected several times during the first month after establishment, and survival was near 100% in all cases. Measurements, including tree height, stem caliper, leaf number, and incidence of *Melampsora* rust, were completed during September at all test sites.

A plan to expand the regional testing program to include northern Minnesota was prepared in consultation with the Natural Resources Research Institute, Duluth, MN, and the Agricultural Utilization Research Institute, Crookston, MN. We will select new *P. deltoides* parental plants from high pH sites in northwestern Minnesota to identify or develop clones that tolerate a combination of high soil pH and severe northern winters.

Major Project Reports: None.

Summary Date: October 1995

Selection and Breeding of Pest-Resistant Clones of *Populus* for Biomass Energy Production in the North Central United States

Directing Organization:

U.S. Department of Energy (DOE)
through the
Oak Ridge National Laboratory (ORNL)
P.O. Box 2008
Oak Ridge, TN 37831-6422

Project Manager: G.A. Tuskan

Telephone: (423) 576-6830

Contractor:

Iowa State University
Ames, IA 50011

Principal Investigators: R.B. Hall, E.R. Hart,
and H.S. McNabb, Jr.

Telephone: (515) 294-1453

Contract Number: 19X43391C

Contract Funding:

FY 1991: \$129,000 (DOE)
FY 1992: \$130,000 (DOE)
FY 1993: \$150,000 (DOE)
FY 1994: \$150,000 (DOE)
FY 1995: \$150,000 (DOE)

Objective:

Develop new clones of *Populus* for producing biomass energy in the north central United States.

Approach/Background:

Selecting and breeding for pest resistance, dry weight yield potential, ease of propagation, and screening for pest resistance in hybrid *Populus* populations is emphasized. Each year, new family materials from natural and controlled populations are planted in nursery or field progeny tests. At the end of the first and third growing seasons the most promising individuals are identified and cloned. Cloned selections are then evaluated for two more nursery seasons. Clones that continue to show promise are then distributed to other programs in the region for long-term field testing.

Status/Accomplishments:

In 1995 selections were made in one 3-year-old progeny test of hybrid aspen and in a 1-year-old test of *P. deltoides* parents and offspring. The 1995 nursery test of new clones includes 166 genotypes. All but seven are pure *P. deltoides* selections from our work

during the past 3 years. Two new progeny tests, one in southeast Iowa, the other in northwest Tennessee, were established with 32 families of *P. alba*.

The project is now in its second year of large-scale release of new clones for longer-term field tests. In 1994, three field trials were established in a transect across Iowa using the same set of 50 new clones. In 1995, 60 new clones were entered into regional field trials in Iowa, Michigan, Minnesota, and Wisconsin. In all our trials, many clones or families are exceeding the commercial clone Eugenei in initial growth potential.

Disease evaluations show all *P. trichocarpa* hybrids are susceptible to *Septoria* canker, and some *P. maximowiczii* hybrids seem resistant. *Marssonina* leaf spot has been very heavy in our test plantings for the past several years, with a particularly high incidence on the Eugenei clone. We hypothesize the appearance of a new biotype of *Marssonina brunnea* in central Iowa over the past few years. In our 1995 screening for Melampsora leaf rusts, we identified a parent that is carrying a single gene, dominant trait for resistance.

The clonal preferences of the cottonwood leaf beetle (*Chrysomela scripta*), its impact on tree growth, and its seasonal population cycles are being assessed. Egg mass infestations of 0.5 or higher per terminal cause significant damage. There is high egg and larval mortality in first- and second-generation field populations; a significant portion of this appears to be caused by natural enemies. Artificial wounding studies indicate that when defoliation reaches 75% on the critical LPI leaves, stems and roots incur significant growth losses, even though most of the crown is still undamaged.

Major Project Reports: See bibliography.

Summary Date:

Selection and Breeding of New Switchgrass (*Panicum virgatum*) Varieties for Increased Biomass Production

Directing Organization:

U. S. Department of Energy (DOE)
through the
Oak Ridge National Laboratory (ORNL)
P.O. Box 2008
Oak Ridge, TN 37831-6422

Project Manager: S.B. McLaughlin

Telephone: (423) 574-7358

Contractor:

Department of Agronomy
Oklahoma State University
Oklahoma Agricultural Experiment Station
Stillwater, OK 74078-5269

Principal Investigator: C.M. Taliaferro and
A.A. Hopkins

Telephone: (405) 744-6410

Contract Number: 19X-SL127C

Contract Period: 5/92-4/97

Contract Funding (Source):

FY 1992: \$71,000 (DOE)
FY 1993: \$84,000 (DOE)
FY 1994: \$82,000 (DOE)
FY 1995: \$82,000 (DOE)

Objectives:

- Increase biomass yield potential in switchgrass populations adapted to the south central and southeastern United States
- Characterize basic breeding behavior and determine phylogenetic relationships of ecotypic and/or polyploid forms of the species
- Establish and evaluate a comprehensive germplasm collection.

Approach/Background:

Switchgrass is a polymorphic outcrossing species composed of biotypes that differ in ploidy level or edaphic requirements, or both. Ploidy levels in switchgrass reportedly range from 2x to 12x, and predominant levels are 4x, 6x, and 8x. Two broad ecotypes are designated as "upland" and "lowland" based on edaphic requirements. Biomass yield is being increased by applying recurrent restricted phenotypic selection (RRPS) in four breeding populations designated southern lowland, northern lowland, southern upland, and northern upland. The populations were formulated from switchgrass germplasm from

central and southern states and are respectively adapted to regions or conditions in the south central and southern United States. More than 100 switchgrass germplasm accessions are being evaluated for standard descriptors. Basic breeding behavior and phylogenetic relationships are being assessed through controlled hybridization and progeny evaluations.

Status/Accomplishments:

Three cycles of RRPS were completed in each population. Experimental synthetic varieties were produced from elite plants identified from the breeding nurseries. Sixteen populations, which consist of C₀, C₁, and C₂ generations from each population, plus four synthetic varieties, were established in four field tests in Spring 1995 to assess agronomic performance and response to selection. The tests consist of solid seeded and space planted nurseries at each of two Oklahoma locations. Seed of four new synthetic varieties was produced in 1995.

A diverse switchgrass germplasm collection of about 100 accessions was assembled from commercial varieties and native stands. Descriptor data were collected for 2 years. Flow cytometry procedures were adapted to determine ploidy level. Plants from selected germplasms were incorporated into the breeding populations.

Preliminary results from crossing studies that encompass thousands of hybridization attempts indicate a strong genetic barrier between ploidy levels/ecotypes.

Major Project Reports: See bibliography.

Summary Date: September 1995

Septoria Pathosystem Studies for *Populus*

Directing Organization:

U.S. Department of Energy (DOE)
through the
Oak Ridge National Laboratory (ORNL)
P.O. Box 2008
Oak Ridge, TN 37831-6422

Project Manager: G.A. Tuskan

Telephone: (423) 576-8141

Contractor:

North Central Forest Experiment Station
USDA Forest Service
St. Paul, MN 55108

Principal Investigator: M.E. Ostry

Telephone: (612) 649-5113

Contract Number: DE-AI05-950R22434

Contract Period: 7/95–5/2000

Contract Funding (Source):

FY 1995: \$35,000 (DOE)

Objectives:

- Validate and characterize field resistance expressed by somaclones
- Assess the level of pathogenic and molecular genetic variation in *Septoria* spp
- Monitor disease effects in poplar trials.

Approach/Background:

We successfully increased the resistance of clone NE 299 (*Populus nigra* var *betulifolia* x *P. trichocarpa*) to *Septoria* leaf spot and canker. Clone NE 308 (*P. charkowiensis* x *P. incassata*) grows rapidly and is tolerant to drought, so it was chosen to further test somaclonal selection to rapidly improve its disease resistance. Somaclones were generated, allowed to grow for several months, and screened for disease resistance. Selected somaclones and controls are being field tested in replicated plantings.

Septoria spp. caused serious leaf and stem diseases. *S. populicola* is found in the Pacific Northwest and on native poplars elsewhere in North America. *S. musiva* is commonly found on poplars in North America, but not in the Pacific Northwest. *Septoria* spp. isolate morphometrics were compared using replicated growth tests, and by measuring conidial dimensions microscopically. Differences in isolate pathogenicity were assessed using *in vitro* inoculations of leaf tissue and stems of poplar host differentials. Genetic structure

and variability of the pathogen populations were analyzed using random amplified polymorphic DNA markers based on the polymerase chain reaction.

Hybrid poplar clonal trials are assessed annually for resistance to the major limiting diseases. Clones were ranked as to disease resistance, growth, and survival.

Status/Accomplishments:

Somaclonal selection was used to increase resistance to *S. musiva*. Of 486 NE 308 somaclones, 29 tested resistant in two repeated leaf disk assays. The resistant somaclones, susceptible somaclone controls, and donor control plants were established in a replicated field planting. The trees will be assessed annually for survival, growth, and disease incidence and severity.

The genetic and pathogenic variability within *S. musiva* and *S. populicola* were assessed. More than 1,000 *Septoria* spp. isolates were recovered from 50 hybrid poplar and aspen clones and native poplars. Isolates were collected from 21 locations. A group of 162 isolates was highly variable in color, sporulation, morphology, and growth rate on artificial media. Pathogenicity of 27 isolates vary widely, and variations in host specificity were detected, using a leaf disk assay on susceptible and resistant hybrid poplar clones. Stem inoculations using 10 isolates from eight hybrid clones and balsam poplar indicated variation in canker development among hybrid poplar host differentials.

Poplar selections in the clonal trials established in the north central United States were monitored for resistance to the major limiting diseases. This has resulted in the identification of a group of clones that have exhibited good growth and a high level of resistance or tolerance to disease over a range of sites. The common set of clones across a wide range of sites has also allowed us to monitor the pathogen populations within them, and has facilitated the collections of various fungi for identification and comparison purposes.

Major Project Reports: See bibliography.

Summary Date: September 1995

Short-Rotation Forest Plantations in Brazil

Directing Organization:

U.S. Department of Energy (DOE)
through the
Oak Ridge National Laboratory (ORNL)
P.O. Box 2008
Oak Ridge, TN 37831-6422

Project Manager: L.L. Wright

Telephone: (423) 574-7378

Contractor:

Department of Forest Sciences
Colorado State University
Ft. Collins, CO 80523

Principle Investigator: D.R. Betters

Telephone: (970) 491-5433

Contract Number: 19X-SM842-V

Contract Period: 4/94-9/95

Contract Funding:

FY 1993: \$20,000
FY 1994: \$30,000
FY 1995: \$25,000

Objectives:

- Facilitate and provide qualitative and quantitative data exchange that deal with short-rotation plantation economics, yields, and cultural treatments
- Describe real or perceived environmental problems and benefits of large short-rotation plantations in Brazil, including effects on biodiversity, nutrients in soils, carbon storage, and the effects of environmental regulations
- Provide case studies of successful ventures that use various types of woody biomass to produce energy in Brazil
- Enhance liaisons with Brazilian biomass-related organizations and provide opportunities to strengthen international cooperation and interaction
- Document the above through major reports and publications in journals and proceedings to disseminate project results and accomplishments.

Approach/Background:

The principal investigator and Dr. Laércio Couto, Department of Forestry, Federal University of Vicoso (UFV) are responsible for meeting the project objectives. Dr. Couto was a visiting professor at Colorado State University from April 1994 to October

1994, and is now involved with the project as part of the faculty at UFV.

Status/Accomplishments:

Economic, yield, and cultural treatment data were obtained from four Brazilian companies: Duratex, Gerdau, Champion, and Copener. These data were augmented by pertinent information contained in theses of graduate students at the Federal University of Vicoso. A major effort to collect additional data is ongoing.

A proposal involving ORNL entitled "Database for Short Rotation Forest Plantations—An International Partnership" was submitted for funding by the National Science Foundation and the USDA Forest Service International Programs division. If funded, it will provide additional support for data collection and exchange.

The principal investigator and Lynn Wright, deputy program manager of the Biofuels Feedstock Development Program visited several forest companies, universities, and government organizations in Brazil that do biomass research or are interested in using biomass for energy. They established new contacts and generated substantial interest on the part of Brazilian organizations. As a result, UFV's president and vice president for research and Aracruz Celulose, a leading short-rotation plantation company visited the United States and solidified the working relationships.

Major Project Reports: See bibliography.

Summary Date: September 1995

Switchgrass as a Biofuels Crop for the Upper Southeast: Variety Trials and Cultural Improvements

Directing Organization:

U.S. Department of Energy (DOE)
through the
Oak Ridge National Laboratory (ORNL)
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Project Manager:

S.B. McLaughlin

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Contractor:

Virginia Polytechnic Institute and State University
Blacksburg, VA 24061

Principal Investigators:

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and W.L. Daniels

Telephone: (540) 231-9778

Contract Number: 19X-SK098C

Contract Period: 5/92-4/97

Contract Funding (Source):

FY 1992: \$67,000 (DOE)
FY 1993: \$85,000 (DOE)
FY 1994: \$75,000 (DOE)
FY 1995: \$75,000 (DOE)

Objectives:

- Evaluate the productivity of switchgrass varieties adapted to the upper southeastern United States and managed under two harvest regimes
- Refine no-till establishment practices for switchgrass that will include considerations of insecticides, planting dates, and seed quality (dormancy)
- Examine the over-winter losses of standing switchgrass biomass.

Approach/Background:

Switchgrass has good potential as a biofuels feedstock, but more information is needed on its establishment and management to optimize productivity regionally. Several field and laboratory studies were undertaken to assess yield and other responses to management. The largest is a five-state, six-variety, cutting-management, and maximum-yield trial. Other work involves studies to consistently and successfully establish under a variety of conditions.

Status/Accomplishments:

A regional variety-screening study was established in 1992 at eight sites in Kentucky, North Carolina, Tennessee, Virginia, and West Virginia. Yields from the 1992 growing season ranged from 0 to 8 Mg/ha. In 1993, the yields ranged up to 19 Mg/ha for the best variety at one site, and average yields within a site varied from 5.6 to 14.6 Mg/ha. Severe, early-season drought accounted for the lower yields at two locations. "Kanlow" and "Alamo" were among the more productive varieties. Two harvests (one in mid-summer and another at the end of the season) provided about 25% more yield than a single cutting at the end of the season. In 1994, the maximum yield for any variety at any site was 24.6 Mg/ha. Yields averaged across varieties within a site ranged from 8.5 to 22.5 Mg/ha. Two cuttings provided an average yield of 15.0 Mg/ha versus 11.7 Mg/ha for a single harvest at the end of the season. "Shelter" was generally less productive than the other varieties, especially when harvested only once.

Studies with delayed harvests revealed that harvestable biomass declines between early September and the end of the season. This appears to be related to translocation of dry matter to below-ground parts. There was no significant decline in standing biomass from November through February.

Recently harvested switchgrass seeds exhibited high levels of dormancy; germinability was often 10% or less. Dormancy was broken by several treatments: exposure of wet seeds to 10°C for 14 to 35 days, mechanical or acid scarification of the seed covering, and dry storage (after-ripening). An accelerated after-ripening (by exposing dry seeds to temperatures of 50° to 60°C for 5 to 30 days) is a feasible way to relieve much of the dormancy, but the exposure to higher temperatures poses risk of loss of vigor, especially if seed moisture is elevated (>7%).

Major Project Reports: See bibliography.

Summary Date: September 1995

Switchgrass Cultivars and Cultural Methods for Biomass Production in the South Central United States

Directing Organization:

U.S. Department of Energy (DOE)
through the
Oak Ridge National Laboratory (ORNL)
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Project Manager: S.B. McLaughlin

Telephone: (423) 574-7358

Contractor:

Texas Agricultural Experiment Station
Texas A&M University
Stephenville, TX 76401

Principal Investigators: M.A. Sanderson,
J.C. Read, W.R. Ocumpaugh, M.A. Hussey,
and C. Tischler

Telephone: (817) 968-4144

Contract Number: 19X-SL128C

Contract Period: 5/92-4/97

Contract Funding (Source):

FY 1992: \$85,000 (DOE)

FY 1993: \$85,000 (DOE)

FY 1994: \$85,000 (DOE)

FY 1995: \$94,000 (DOE)

Objectives:

- Obtain data on adapting switchgrass cultivars in the south central United States
- Develop improved management practices for producing switchgrass biomass
- Develop germplasm with improved establishment and reduced seed dormancy.

Approach/Background:

A multi-environment approach is used to determine cultivar performance. Genetic and physiological techniques are used to modify seed dormancy and improve establishment of switchgrass. Plot studies are used to examine responses to harvest frequency and timing and soil fertility needs.

Status/Accomplishments:

Alamo switchgrass was the highest yielding cultivar in 1993 and 1994. Caddo and Cave-in-Rock were the lowest yielding cultivars in both years. Caddo and Cave-in-Rock matured in June, whereas the other switchgrasses matured in August and September.

Biomass yield of Alamo switchgrass increased with increasing nitrogen rate at each location in 1992, 1993, 1994, and 1995. There was a small response to 20 kg of P_2O_5 ha^{-1} at Stephenville in 1992, but none to phosphorous fertilizer at Stephenville in 1993 or 1994 or at Beeville in 1993 or 1994. Soils at both locations were low in phosphorous (less than 10 kg ha^{-1} of available phosphorous in the surface 30 cm of soil according to soil test). Switchgrass does not respond to phosphorous fertilizer, which indicates that switchgrass uses phosphorous very efficiently. This may be a result of colonization of switchgrass roots by vesicular-arbuscular mycorrhizae.

At both Dallas and Stephenville, increasing harvest frequency reduced total season biomass yields of Alamo switchgrass in 1993 and 1994. The highest yields at both locations were obtained with a single harvest in September. Delaying the final fall harvest until October or November reduced yields. In the multiple harvest systems, about 40% of the yield was obtained at the first harvest in May.

We have made progress in selecting switchgrass populations for enhanced and reduced crown node (subcoleoptile internode) elevation and reduced post-harvest seed dormancy. These selections may have improved establishment characteristics.

Major Project Reports: See bibliography.

Summary Date: September 1995

Tree Genetic Engineering Research Cooperative

Directing Organization:

U.S. Department of Energy (DOE)
through the
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P.O. Box 2008
Oak Ridge, TN 37831-6422

Project Manager: G.A. Tuskan

Telephone: (423) 576-8141

Contractor:

Oregon State University
Corvallis, OR 97331-7501

Principal Investigators: S.H. Strauss and
K.-H. Han

Telephone: (503) 737-6578

Contract Number: 85X-ST807V

Contract Period: 3/94-3/99

Contract Funding (Source):

FY 1994: \$50,000 (DOE)
FY 1995: \$55,000 (DOE)

Objective:

Use improved regeneration and transformation methods to develop efficient gene transfer protocols for poplars.

Approach/Background:

We seek to improve transformation by developing means to rapidly customize transformation protocols for individual clones and generalized methods that would improve transformation of a variety of clones and species.

Status/Accomplishments:

In Experiment 1 we developed a way to transform model clones at high frequency. The goal of this work is to generate transformants with transgenes for sterility, and for glyphosate and insect resistance for near-term field testing. An indirect organogenesis approach substantially increased transformation efficiency in hybrid cottonwood. Forty-four transgenic lines with glyphosate resistance transgenes were generated in four triploid cottonwood clones; they will be field tested in 1996 and 1997.

In Experiment 2 we made genotype-independent transformation advances. The goal of this study is to identify major factors that enhance transformation but do not show strong genotype interactions. A current focus of this work is on matrix attachment regions

(MARs). They are sections of DNA that help to coordinate chromosome structure, and can significantly increase uniformity and intensity of transgene expression. We have observed large increases of transgene expression in poplar the first few weeks following cocultivation using a tobacco-derived MAR. Effects on recovery of transformants are currently under study.

Major Project Reports: See bibliography.

Summary Date: September 1995

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Biosyngas

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Index of Current Contractors

Index of Current Contractors

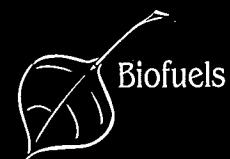
American Energy Crop Association	123
Auburn University	4, 5, 128
Battelle Memorial Institute	53
Belcan Engineering Group, Inc.	95
Bioenergy Development Corporation	78
Colorado State University	6, 137
Cornell University	23, 24
Dartmouth College	15, 16
Dyncorp	96, 101-107
Ecobalance, Inc.	41
George Mason University	44
Hauser Chemical Research, Inc.	28, 33
Hazen Research, Inc.	7
Iowa State University	80, 81, 134
John Brown Engineers and Contractors	32
MARC-IV	40
Mississippi State University	130
National Renewable Energy Laboratory	3, 13, 14, 21, 22, 29-31, 37-43, 47-52, 54, 55, 59-65, 69-77, 93, 94
National Audubon Society	85, 116
New Uses Council, Inc.	82
Oak Ridge National Laboratory	83, 111, 114, 120, 121, 131, 132
Ohio State University	17
Oklahoma State University	135
Oregon State University	8, 140
Pacific International Coalition for High Technology Research	97
Purdue University	9, 117
Rutgers University	26, 27
Southern Research Institute	18
State University of New York	113
Technology and Management Services, Inc.	109
Tennessee Valley Authority	79
Texas A&M University	10, 86, 139
U.S. Department of Agriculture	125
U.S. Forest Service	112, 115, 119, 122, 133, 136
University of Minnesota	84
University of Florida	98
University of Kentucky	87
University of Rochester	25
University of Wisconsin	20
University of Washington	124, 129
University of Toronto	19
University of Tennessee	118
Virginia Polytechnic Institute	11, 88, 138
WesMin Resource Conservation & Development Council	127
Western Washington Research and Extension Center	124
Weyerhauser Company	99
Wisconsin Energy Bureau	89
Wood Industries Company	100
Xylan, Inc.	12





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