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ENVIRONMENTAL SCIENCES DIVISION

**BIOFUELS FEEDSTOCK DEVELOPMENT PROGRAM
ANNUAL PROGRESS REPORT FOR 1992**

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OVERVIEW

INTRODUCTION

The Department of Energy's (DOE's) Biofuels Feedstock Development Program (BFDP) leads the nation in the research, development, and demonstration of environmentally acceptable and commercially viable dedicated feedstock supply systems (DFSS). The goals of the program include technology development and technology implementation. BFDP's overriding goal is to develop a variety of dedicated biomass feedstock technologies that could supply as much as 15% (up to 20 GJ) of the primary energy produced in the United States. A second goal is to ensure successful technology acceptance and implementation.

DFSS have the potential of providing a very large renewable source of biomass supplies for energy, fiber, and chemicals. DFSS incorporate the production of specialized tree and grass crops with appropriate systems for harvest, storage, and delivery. With appropriate technology and planning, DFSS can meet high standards of environmental quality on a wide variety of cropland types, including some types of environmentally sensitive land. Production of DFSS for energy on a large scale could provide a significant source of renewable energy that could enable reduced reliance on fossil fuel sources. Several evaluations of solutions for preventing or delaying global warming indicate that biomass energy must become a significant energy resource. Production of DFSS for a large energy market could revitalize the rural economy and remove some of the burden of federal subsidy payments to farmers. The BFDP has been charged by DOE with leading the research, development, and demonstration required

to convert potential benefits into real benefits.

The BFDP has been managed by staff in the Environmental Sciences Division (ESD) of Oak Ridge National Laboratory (ORNL) for DOE's Biofuels Systems Division since 1978. Most of the technology research and development work has been performed by subcontractors in academic, private, and government institutions. The information development and technology transfer activities required for ensuring technology acceptance has been performed by both ORNL staff and subcontractors or cooperators. The program complements and collaborates with biomass conversion research supported by at least three different divisions and offices within DOE.

BFDP researchers have evaluated a wide variety of plants that could be used as dedicated biomass feedstocks and the types of land on which they can be produced. Numerous cropping and harvesting methods have been considered, and the production costs associated with each have been evaluated. Exciting new techniques for crop improvement and modification have been developed. The program currently coordinates an extensive network of integrated research on crop development (Appendix 1), maintains a unique data base on crop production techniques, and performs resource and economic analysis of DFSS. The environmental implications of biomass feedstock production are being evaluated on local, national, and global scales.

The BFDP shares the responsibility of capturing the potential of biomass energy with biomass conversion research programs supported by DOE. The BFDP is most closely linked to the biomass-to-liquid fuel

research conducted by the National Renewable Energy Laboratory (NREL) and supported by the Biofuels Systems Division under the DOE Office of Transportation Technology. The U.S. interest in reducing oil imports places a high priority on developing biofuels.

Utility interest in biomass-to-electricity technology is expanding rapidly because of increased global warming concerns and pending regulations on CO₂ emissions. Thus, the technology and information resources developed by the BFDP are also being heavily relied upon by the Solar Thermal and Biomass Power Program under the DOE Office of Utility Technologies.

A third source of interest in biomass feedstocks is emerging within DOE's Office of Industrial Technologies as programs to increase industrial energy efficiency recognize the potential of biomass feedstocks and as new ways are found to produce chemicals from biomass feedstocks.

Industries interested in biomass resources indicate that dependability and reliability of biomass feedstock supplies are two of their largest concerns. With biomass conversion technologies approaching demonstration phases, with global environmental concerns accelerating, and with farmers searching for new crops and markets, the importance of the research managed by the BFDP is expected to increase dramatically. The past 14 years of research management has given ORNL the experience and knowledge needed for leading a well-focused effort in converting the potential of biomass energy to a reality.

APPROACH

The BFDP provides leadership in the development of DFSS in the following ways. It integrates agriculture, energy, and environmental objectives in developing

concepts of integrated biomass energy systems. It seeks and fosters the best research, development, and demonstration projects in the private, academic, and government sectors. It strives to ensure that information on biomass supply systems is timely, accurate, understandable, and accessible.

The BFDP has organized its research, analysis, and management resources to meet near-term needs and to prepare for future expectations. Research in 1992 was conducted under five task areas including woody crop development, herbaceous crop development, environmental research and analysis, economic analysis and integration, and information management. Each task leader managed a mixture of subcontracts, supervised internal work, and conducted relevant individual research and analysis. All of the efforts have been focused on facilitating the commercialization of integrated, environmentally sound, biomass energy systems.

The woody and herbaceous crop tasks both have three key deliverables: development of (1) plant culture technologies, (2) appropriate, superior plant materials, and (3) developed germ-plasm resources. Research is currently being focused on two general regions, the north central/midwest region and the south/southeast region for the development of superior plant materials, germ-plasm resources, and cropping systems technology. Other technologies such as tools for genetic manipulation and improvement, site quality/site index prediction functions, vegetative propagation techniques, and physiological characterization of root growth are being developed at specific locations with generic application to any region of the United States. The current program strategy is to develop new varieties of switchgrass and new clones of poplars for the north central/Midwest and the South/Southeast regions. Two breeding centers for

switchgrass currently exist—Oklahoma State University and the USDA Agricultural Research Service at Lincoln, Nebraska. The breeding centers are assembling breeding materials and developing superior seed sources for evaluation by collaborators. Collaborators are concentrating on testing currently available varieties, improving agronomic techniques, and developing tissue culture techniques. Two breeding centers for *Populus* also exist, and a third is being planned in FY 1993. The oldest center is led by the University of Washington in collaboration with Washington State University and industry collaborators. The newer center is led by Iowa State University in collaboration with several other universities. The *Populus* breeding centers involve integrated crop research connected with a breeding program focussed on assembling breeding materials, developing superior pedigrees, and releasing clones for widespread testing. The connected supportive *Populus* research consists of applicable physiology, molecular biology, pathology, entomology, and silviculture. These crop development strategies should result in prompt, cost-effective gains in research knowledge as well as production of the deliverables noted above for switchgrass and *Populus*. Crop development centers for additional species need to be established but are not planned at this time.

The BFDP economic and environmental tasks are closely linked. The key deliverables of these tasks are to (1) define energy crop price-quantity relationships, (2) identify and document the ecologically important and environmentally regulated effects of biomass commercialization, and (3) bring these efforts together to address citing issues and define viable ways to optimize environmental benefits within economic

constraints. Data collection and analysis aimed at predicting potential environmental and economic changes (positive and negative) resulting from commercialization of energy crop production is gaining more attention. The economic and environmental tasks also include the development of concepts of integrated biomass energy systems that could contribute to the successful demonstration of integrated biomass energy systems. These concepts are being developed in close linkage among (1) researchers from NREL working on both liquid fuel and biomass electric technologies, (2) analysts from the Electric Power Research Institute and individual utilities, (3) environmental groups such as the Audubon Society and the Nature Conservancy, (4) fiber feedstock production managers in the wood products industry, and (5) managers of similar research programs in other parts of the world. The linkages are occurring through cost-shared research, presentations at workshops and meetings, roundtable discussions, data and information exchange, and site visits. This dialogue with diverse interested parties is considered necessary at this time to ensure that the broadest public interest is considered in the development of biomass energy technology.

The BFDP information management task has a vital role in meeting customer needs for research information on energy crop systems. Better information management and tracking systems are being developed. Other information centers are being evaluated as models for enhancing our technology transfer efforts. The newsletter, *Energy Crops Forum*, being produced by the information task leader is facilitating the necessary communication among energy crop researchers, potential energy crop producers, and potential energy crop users.

KEY 1992 ACCOMPLISHMENTS

The purpose of this report is to highlight the status and accomplishments of the research that is currently being funded by the BFDP. Highlights summarized here and additional accomplishments are described in more detail in the sections associated with each major program task. A few key accomplishments include

1. Development of a methodology for doing a cost-supply analysis for energy crops and the application of that methodology to looking at possible land use changes around a specific energy facility in East Tennessee.
2. Preliminary documentation of the relationship between woody crop plantation locations and bird diversity at sites in the Midwest, Canada, and the Pacific Northwest supplied indications that woody crop plantations could be beneficial to biodiversity.
3. Receipt of a \$150,000 per year grant from the DOE/National Science Foundation (NSF)/U.S. Department of Agriculture (USDA) Joint Program on Collaborative Research in Biology by BFDP subcontractor, University of Washington, which will allow completion of a genetic linkage map for poplar clones developed with BFDP funding.
4. An award of a 3-year, \$200,000 per year grant was received by ESD staff for the purpose of introducing plant hormones into hybrid poplar in an effort to enhance *Populus* feedstock quality. This work was made feasible by the investment of the BFDP program in the capital equipment

needed to make an ESD biotechnology research laboratory operational.

5. The initiation of integrated switchgrass variety trials, breeding research, and biotechnology research for the south/southeast region.
6. Development of a data base management system for documenting the results of herbaceous energy crop field trials.
7. Publication of three issues of *Energy Crops Forum* and development of a readership of over 2300 individuals or organizations as determined by positive responses on questionnaires.

FUTURE DIRECTIONS

The BFDP is undergoing considerable change in emphasis and direction. Numerous integration analysis and technology transfer activities have been added to the program without any increase in funding. Changes required to accommodate this adjustment are as follows.

- Nearly all of the species and silvicultural screening trials for both woody and herbaceous species have been brought to a close.
- Linked physiology/breeding studies for all woody crops other than poplars are also being brought to a close in 1993 or 1994.
- Crop development efforts will concentrate on poplars and switchgrass and may include a new cost-shared breeding effort for woody crops for the South/Southeast.

- Ongoing work in economic and environmental analysis will be expanded and combined together under a new task called "Systems Integration and Analysis." Work will include fuel cycle analysis and risk assessments.
- Geographic information systems (GIS) will be used to address landscape ecology issues.
- The "Environmental Research" task will concentrate on collecting data needed for evaluating environmental effects of DFSS and for improving the environmental soundness of DFSS.
- ORNL researchers will determine the feasibility of genetically altering the composition of energy crops to enhance the efficiency of conversion processes.
- Additional effort will be put into organizing and documenting the unique information resources of BFDP to make them more accessible and available for use by a wide variety of interested customers. The program strives to be responsive to current needs while continuing to support the high-quality, long-term research efforts required in the development of new crops.
- site-specific guidelines for best crop management techniques.
- Expansion of environmental research on biodiversity, sustainability, and landscape ecology to develop environmentally sound crop production techniques.
- Creation of an energy crop information center, integrated with NREL, to facilitate getting research information to extension networks, energy producers, and farmers.
- Creation of extension networks through traditional USDA channels for getting information to potential feedstock producers.
- Development of lower-cost harvest, handling, and transportation options for energy crops through systems modeling and new equipment development.
- Initiation of crop improvement programs with a greater variety of crops and in a greater number of locations.
- Expansion of plant sciences research on topics such as drought and pest tolerance, photosynthesis, and genetic modification of plants.

Many additional research, development, integration, and demonstration needs are recognized by the program but cannot currently be met under anticipated budgets. A few of these needs are

- Initiation of a few biofuels systems demonstrations and development of

A major BFDP effort in FY 1993 will include articulating more clearly what needs to be done, suggesting logical avenues for pursuing the efforts, and working to expand the impact of the program through cooperative efforts with both public and private organizations.

1992 RESEARCH HIGHLIGHTS AND ACCOMPLISHMENTS

SHORT-ROTATION WOODY CROP RESEARCH

Background and Research Strategy

Dedicated wood energy crops generally consist of deciduous hardwood tree species that have been selected for qualities suitable for biofuels conversion, such as rapid early growth, pest resistance, broad general adaptability, high cellulose content, and the ability to regenerate via coppice sprouts. Historically, research in the BFDP has involved breeding and genetic improvement, physiological characterization, cultural management testing, and cultivar/clone site trials for several model species. Through this research, dry average yields in some regions of the United States have increased from 4.5 to 20 Mg·ha⁻¹·year⁻¹ on 6- to 10-year rotations, and end-use costs have decreased from \$4.00 to \$3.10 per GJ.

There are currently 13 ongoing short-rotation woody crops (SRWC) research projects within the BFDP. These projects are designed to develop specialized wood energy crops for the regions of the United States where land availability and climate are favorable for the establishment of biomass-based energy industry. In the past, four model species have been selected for research and development based on their potential to be highly productive on a broad range of sites under environmentally sound management practices and wood quality characteristics suitable for economical conversion to liquid fuels. Because of budgetary reductions, the scheduled closing of several projects, and a slight redirecting of several projects, the majority of the SRWC research in FY 1992 has dealt with *Populus*.

Although much is known about the *Populus* genus, opportunities exist for improved productivity, energy qualities, and adaptability to site variation and environmental stresses. To achieve these goals, selection and breeding based on traditional tree breeding criteria have been used to provide immediate gains, while physiological research in association with biotechnology has been used to delineate traits for long-term improvement of *Populus* species as energy feedstocks.

Populus Research Progress

Several separate but connected activities were completed or initiated in FY 1992 related to *Populus* improvement and crop development. Two of these accomplishments primarily involve in-house activities, two primarily involve subcontracted activities, and two others involve multiple agency activities. These six activities reflect (1) a greater emphasis being placed upon *Populus* improvement and crop development by the BFDP and (2) a larger effort by the BFDP to integrate existing in-house and subcontracted research.

In-house, ESD's biotechnology laboratory is now operational as a result of DOE capital equipment investments over the last 2 years. The purpose of this laboratory is to integrate the techniques of plant tissue culture, DNA isolation and characterization, and genetic transformation into existing, ongoing research activities related to SRWC improvement. As a result of these investments, the BFDP received a 3-year, \$200,000 per year grant through the Laboratory Director's Research and

Development funds to introduce plant hormones genes into hybrid poplar in an effort to enhance *Populus* feedstock quality.

The second in-house activity involves the completion of the physiological and biochemical evaluation of drought tolerance in hybrid poplars. Through the use of a six-clone pedigree, developed as part of the BFDP activity at the University of Washington, drought tolerance via osmotic adjustment as been demonstrated in hybrid poplar. In this pedigree, water stress-tolerant clones under stress were able to grow at a rate of ~ 55% of well-watered plants, compared with intolerant clones, which grew at ~ 45% of well-watered plants. Pressure volume analysis indicates that water stress-tolerant clones show an osmotic adjustment of 0.25 MPa not seen in the intolerant clones. Two separate manuscripts and a possible joint experiment with the University of Washington/Boise Cascade in eastern Washington have resulted from this work.

A study with the U.S. Forest Service in Grand Rapids to examine the relationship between plantation productivity and soil and climatic characteristics in the north-central region was completed. Soil and climatic condition varied greatly across the plantation network. Of all the climatic data examined, cooling degree days was found to be significantly related to tree biomass, based on a curvilinear model. The validity of this model was supported by the below average growth witnessed in all poplar plantings in the north-central region under this summer's cooler than average growing conditions. Unexpectedly, soils data were generally not related to tree growth. Depth to water table, however, was weakly related to tree biomass. Future analyses will have to be conducted before soils information is excluded as a factor influencing poplar productivity.

Iowa State University has completed its 1992 evaluations of the 1991 entries in a nursery screening study. In total, 74 clones were screened for leaf diseases, insect feeding preference, growth rate, branching habit, and rooting success. The best clones in terms of growth rate were pure *P. deltoides*; the best hybrid clone was a *P. maximowiczii* x *P. nigra*. All clones in the 1991 screening trial will be screened again in 1993 in larger clonal blocks before the poorer performing clones are eliminated. After the second screening, the better clones will be released into small regional screening trials to identify the top 1-2% of the clones for release into operational testing. A total of 42 clones from the 1990 larger clonal block test have been released into the small regional screening trials.

The University of Washington, along with numerous collaborators, has been awarded a 3-year, \$150,000 per year grant from the DOE/NSF/USDA Joint Program on Collaborative Research in Plant Biology to coordinate the molecular genetics research on *Populus*. As a result of this award, the University of Washington will coordinate the completion of a genetic linkage map for *Populus*, disseminate information and plant materials to researchers, and facilitate the integration of research results. These activities will benefit the BFDP at no cost by expanding the network of researchers studying on the *Populus* pedigree developed with BFDP funding.

The second multiagency activity involves the formation of the North-Central *Populus* Research Consortium. The purpose of this consortium is to integrate *Populus* research activities that are currently taking place in the north-central region in an effort to remove duplication and to increase research output per unit dollar invested. There are 5 research agencies and 12 researchers

involved in the consortium. The first year's activity involved the exchange of collected germ plasm and the coupling of the breeding research with the laboratory and field testing research. A second meeting is scheduled for early FY 1993 to set consortium objectives for the upcoming year.

Additional SRWC Research Progress

As has been shown in other countries, research solely on a single species invites failure and limited application of results. Thus, continued research related to the genetic improvement of a minimum of two model species for each of the four major short-rotation energy crops regions in the United States remains critical to the successful implementation of a national biomass program for liquid fuels production. This effort, however, remains unfunded. The following summaries report on the four remaining SRWC species under investigation by the BFDP in FY 1992.

Genetic variation in silver maple (Southern Illinois University). Four tissue-culture propagated silver maple provenance field tests have been established in three midwest states; two in 1991 and two in 1992. Clones in these tests represent 4 genotypes from 15 different provenances from across the natural range of silver maple. Each field test contains five replications of four tree plots for each selected clone. First-year survival at all sites was high, averaging 85+ % at each site. The high survival rate is attributed, in part, to the use of 1.25-mil polyethylene mulch within the plantings. Soil moisture condition remained high, and weed competition was eliminated as a result of this mulch. At the end of the first growing season, the best clone within the best provenance reached an average

height of 2.3 m in two growing seasons, more than doubling the average growth for nonselected silver maple seedlings. Deer browsing within the plantations has been successfully controlled through the use of a three-dimensional deer fence.

Willow monoculture viability trial (State University of New York). The BFDP began participating in a monoculture viability trial with State University of New York (SUNY). SUNY is coordinating efforts to establish two 100-acre hybrid willow demonstration farms. This is a cooperative effort involving Electric Power Research Institute, Empire State Electric Energy Research Cooperation, Niagara Mohawk Power Corporation, New York Electric and Gas Corporation, New York State Electric Research and Development Agency, and the University of Toronto. The silvicultural system used in these farms will be modeled after the Swedish system of 3- to 4-year rotations, twin-row planting, coppice regeneration, and mechanical harvesting. Clonal material and site selection for the first 100-acre plantation have been completed; nursery scale-up and site preparation will continue in FY 1993.

Early selection and clonal propagation of sycamore (Mississippi State University). Dry weight yields in a 3-year-old clonal sycamore planting have been analyzed. Average aboveground dry weight was 12.8 dry Mg·ha⁻¹·year⁻¹ (44% of the total tree dry weight). Total tree dry weights have been partitioned among the component parts, with 40% of the fixed carbon occurring belowground; half of this dry weight occurred as fine roots. Early selection statistics indicated that 7-month seedling variables such as height and ground-line diameter can be used to predict 2-year field performance. Further data is needed to test rotation age correlations before final recommendation

can be made. Rooted cutting experiments have been completed. Hardwood cuttings taken before bud break from 2-year-old sprouts produced the greatest height (desirable), diameter (desirable), root length (desirable), and mean sprout number (undesirable). Apomixis (i.e., the formation of viable seed in isolated, nonpollinated flowers) is being investigated and verified by genetic fingerprinting techniques. If valid, apomixis may prove to be the most reliable, useful method of vegetatively propagating mature sycamore genotypes.

Genetic improvement of black locust (University of Georgia). Third- and fourth-year field measurements have been obtained from the irrigated, fertilized, north central Georgia progeny test containing 24 open-pollinated families of black locust. The best family in the best plots produced 8 dry Mg·ha⁻¹·year⁻¹. Procedures for obtaining rooted cuttings have been established, with greenwood cuttings dipped for 5 s in 8000⁺ ppm IBA and placed in Oasis rooting medium under intermittent mist producing 80% or higher rooting success across 23 different clones. Somatic embryogenic cultures have been established from excised immature embryos placed on WPM with 3 mg/L 2,4-D and 0.25 mg/L BA. The somatic embryogenic cultures have been used in gene transformation experiments. Biolistic transformation techniques have led to transient expression of two selectable marker genes, NPT II and GUS. Ultimately, stable transformation involving stem borer-resistance genes will be the long-term goal of this research.

Future Plans

The long-term health and security of a renewable, dedicated biomass energy crop industry will depend on actions taken

today. As commercialization approaches, the BFDP SRWC research mission needs to provide those agencies, institutions, and/or corporations interested in commercialization with three deliverables: (1) developed silviculture technologies; (2) appropriate, superior plant materials; and (3) developed germ plasm resources. Developed technologies would include systems for genetic manipulation and improvement, silvicultural systems, harvesting systems, etc. Appropriate plant materials would include adapted, high-yielding, pest-resistant, environmentally stable clones. Developed germ plasm resources would include broad, systematically selected, managed collections of species' germ plasm. Short-term, crisis-driven research approaches will not allow this to happen, regardless of how appropriate or necessary these short-term approaches are.

A desirable approach to achieving these deliverables would involve restructuring SRWC research into seven centers of crop development, three for *Populus* and four for alternate species such as sycamore, silver maple, black locust, and *Salix*. These centers would engage in integrated crop research focussed around a breeding program that focuses on genotype assembly, pedigree development, and clonal release. The associated, supportive research would consist of applicable physiology, molecular biology, pathology, entomology, and silviculture. This research approach would not only lead to the requisite deliverables but should also result in the fastest, most cost-effective gain in terms of understanding these processes. Currently, two such centers exist, with a third planned for *Populus* in FY 1993. No crop development centers for species other than *Populus* are currently being funded by the BFDP.

Anticipated accomplishments with poplars include the development of insect- and disease-resistant poplars. This

research will remain a high priority through 1996, when a set of new clones will be identified based on greenhouse and nursery studies. Field testing of the clones should result in public release throughout 1998 to 2002. It is anticipated that selection of superior *Populus* hybrids will be possible based on molecular marker-assisted selection. Early selection criteria based on physiological parameters will also be available to poplar breeders by 1996. Increased emphasis on selecting and breeding poplar clones for high yields under less than optimum soil and climatic conditions will be required to ensure that SRWC can potentially supply significant quantities of energy to the United States. With the initiation of the woody crop breeding program in the Southeast, it is anticipated that new plant materials may be available by 2002. With accelerated breeding efforts in all regions, it is anticipated that superior selections would be capable of producing 22 dry Mg·ha⁻¹·yr⁻¹ under optimum conditions and 1 to 6 dry Mg·ha⁻¹·yr⁻¹ under average conditions.

In addition to the Crop Development Centers, the SRWC research will need to support short-term task-specific projects that (1) need not be duplicated in each center, (2) have broad application, or (3) are exploratory in nature. The following list includes some of the anticipated task-specific areas for which projects should be initiated.

- Development of site quality/site index prediction functions for poplars in the Midwest and elsewhere in the United States.
- Vegetative propagation of selected sycamore genotypes, including examination of apomixis as a mechanism of clonal propagation.
- Physiological characterization of belowground (i.e., root) growth,

specifically related to adaptation to stress.

- Continue testing and development of stem borer resistance in black locust through the use of biolistic gene transformation techniques.

HERBACEOUS ENERGY CROPS RESEARCH

Background and Research Strategy

Research on the biofuels potential of herbaceous crops has developed much more recently than has that for woody crops. The objectives have been very similar in some respects with a common emphasis on high-yielding crops that can be grown economically over a wide area with minimum adverse effect on the environment. Although herbaceous crops do not currently provide quite as wide a spectrum of product endpoints as woody crops do, their very high productivity, high adaptability, and landowner compatibility provide important incentives for their incorporation into the BFDP.

In 1984, a series of ten herbaceous research projects began at widespread locations across the eastern and midwestern United States. A total of 35 species was examined in these initial screening studies, which were designed to examine yield potential, biochemical composition, and best management practices across a wide diversity of sites. The completion of several of these studies and the examination of data on yield potential, production economics, and regional site potential, led in 1991 to the selection of a perennial forage grass, switchgrass (*Panicum virgatum*), as a model species for further research.

The rationale for selection of a single species was to concentrate and thereby improve the overall efficiency of the many

interrelated aspects of research that were seen as requisite for biofuels production. Although more than one species will certainly be required ultimately, switchgrass was seen as an excellent beginning with the available programmatic resources.

The selection of switchgrass as a model species was based on several important considerations. As a widely adapted endemic species of the tall grass prairies, switchgrass has demonstrated a capacity for high yields on relatively poor quality sites. Maximum yields on test plots in Auburn, Alabama, have been 33 dry Mg·ha⁻¹·year⁻¹, well above the production level considered prerequisite for a successful biofuels industry. A large and deep root system is the key to high production and soil improvement on poor quality sites. Research at Virginia Polytechnic Institute and State University has shown that soil organic carbon was increased by 30% during a 4-year cycle, indicating that switchgrass has a significant capacity to improve soil quality by sequestering carbon belowground. Improved erosion control, reduced fertilizer and pesticide requirements, and a capacity for providing wildlife cover are additional positive environmental attributes. An important quality of switchgrass is its strong potential appeal to landowners, for whom cultivation of a perennial crop that can be grown, harvested, and stored with conventional equipment represents an easy interface with current agricultural practices.

Summary of Preceding Cultural and Variety Selection Research Progress

During the past year, research on herbaceous biofuels crops has included the completion of species screening and productivity research (at Auburn University and the University of Kentucky) and the continuation of three projects designed to

evaluate cultural and genetic attributes of predominantly perennial grass species and associated cultural practices for the upper Midwest (at USDA Lincoln, North-Dakota State, and Iowa State).

A review of the past 7 years of herbaceous crop screening research, some of which will be completed during the current year, reveals several significant measures of progress. A summary of progress in productivity research that has resulted from this work is provided in Fig. 1. It generalizes the relative improvement of yields or establishment success in research plots with various cultural treatments and/or selection procedures. Obviously, these improvements do not have linear additive potential in terms of final yield attained, but do demonstrate on a relative scale gains that can be made through productivity research. Most notable are the yield improvements (110%) made in the choice of our initial principal switchgrass cultivar, Cave-in-Rock, compared with average yields for hay, and the further improvement (180%) made with selection of the highest-yielding variety to date, Alamo. Site quality, harvest frequency, and weed control all have been shown to be important factors in promoting or protecting switchgrass yields. Nitrogen fertilization to date has been effective only on poorer quality sites with typically little or no effect at levels above 70 Kg/ha. On more fertile sites, effects have typically been negative to neutral. Nitrogen use efficiency and its relationship to root/rhizosphere function remains an area of future interest and utility for ecological/economic interactions.

Plant breeding represents the only approach not previously used within the program. In previous grass breeding research, genetic gain in yield has been ~ 5% per cycle. Test of genetic variability in yield and in biochemical constituents known to be related to foliar nutritional

Fig.1. Methods for improving and protecting switchgrass productivity.

value of switchgrass for cattle have been evaluated within the program as a basis of future breeding effort. Significant genetic differences in tissue biochemical content have been found across 23 wild accessions of switchgrass and in 20 developed cultivars. Such information may form the basis of future breeding efforts to select for both yield mass and quality. The utility of several of these nutritive indicators for ethanol yield is currently being evaluated in

a collaborative project with NREL biochemists.

Overall, the initial species screening studies provided the data on which to select the model perennial species, switchgrass, for further programmatic emphasis. In addition, several other promising species were identified, including sorghum and sorghum-sudangrass for the Midwest and tropical grasses for the deep South. The remaining research in this

initial screening effort will be completed in three projects in the upper Midwest during the current year. These sites include North Dakota State, Iowa State, and the USDA-ARS site at Lincoln, Nebraska. The new research described in the following subsections builds heavily on progress made in these and other first-phase screening work.

Important logistical aspects of switchgrass production and handling relative to its use as in biofuels production were also evaluated during the past year. A collaborative study between Purdue University and NREL led to important estimates of the integrity of switchgrass bales under long-term storage practices. Their estimate of a very low 5% loss rate over 10 months (with proper storage conditions) provides encouraging indications of more flexible supply/demand relations for this seasonal perennial crop.

Initiation of New Research Projects

With the release of a Request for Proposals in November of 1991, the process of building on and extending the results obtained during the first research phase began. Important findings from the earlier research that aided in the focus of this new research included the following:

- (1) selection of best-yielding varieties,
- (2) estimates of consistency of high yields across soil types and climatic conditions,
- (3) optimization of fertilization responses and harvesting strategies, and
- (4) quantification of impacts on soil erosion and soil organic matter.

Six new projects were selected by March of 1992 with a focus that was divided between near-term, production-oriented research on the best available varieties and the longer-term breeding, physiology, and biotechnology requirements for protecting and improving future yields. Collectively, these six new research projects combine

both near-term production research with longer-term development needs in an approximate 3:2 ratio.

The six new research projects included three regional field trials to verify and improve yield potential of selected cultivars, a breeding project to search for new improved varieties, a physiology project to develop indices of yield potential, and a tissue culture project to develop advanced techniques for plant propagation. Progress in each of these areas is highlighted below.

Regional field trials and cultural improvements. Three projects, at Virginia Polytechnic Institute, Auburn University, and Texas A&M University, were selected to represent, respectively, the mid-Atlantic, Southeast, and southcentral subregions of the targeted southern United States. A total of 18 of the planned 19 field sites for switchgrass variety evaluations were established in 1992. Research on establishment techniques, fertilization requirements, cultural management, and harvesting strategies are important components of this research. In addition, at most sites initial soil characterization will allow measurement of changes in soil nutrient status, including soil organic carbon, over time.

Plant breeding. A single project at Oklahoma State University was selected for efforts to improve existing lines of switchgrass for biomass potential. Initial efforts are focusing on breeding across four populations representing upland and lowland ecotypes. Both hexaploid and tetraploid genotypes are represented within each ecotype. A new detached culm technique has been successfully tested for switchgrass for the first time in this work and has allowed the first of three breeding cycles of Recurrent Restricted Phenotypic Selection to be completed in the first growing season. A switchgrass nursery has

been established, with 63 accessions having been obtained to date from several sources.

Physiology. Plant physiological studies are centered at ORNL and emphasize the development of physiological indicators for selection and evaluation of superior plant growth potential. To date, measurements of foliar gas exchange, photosynthesis and dark respiration, and biomass partitioning have been used in greenhouse studies. These indicators have been used to contrast the carbon gain potential of six upland and six lowland ecotypes over two cutting cycles. A lack of significant differences among genotypes under these conditions suggested that genotype-site adaptation in the field plays a very important role in yield potential and will lead to increased emphasis on parallel physiological evaluation in field studies during the upcoming season.

Tissue culture studies. Tissue culture studies begun at The University of Tennessee in July of 1992 have already achieved remarkable success. Although no formal procedures had developed for producing switchgrass from tissue culture before the project began, a variety of techniques for producing switchgrass callus have already been successfully tested. Node culture, shoot culture, and mature embryo culture of two cultivars have all been shown to produce callus tissue from which seedlings have been regenerated. Flower production from callus, in one case, has provided some indication that tissue culture systems for selection as well as propagation may be an important tool in future switchgrass yield improvement research.

Future Plans

The new switchgrass research projects offer some exciting challenges for

integrating production, breeding, propagation, and physiology research in the future. As newly established research plots across the Southeast move into their more productive postestablishment years, the associated basic and applied research on yield limiting factors will increase the amount of information gained from these studies. Opportunities for integrating physiology, breeding, and tissue culture techniques will increase as breeding cycles are applied and propagation techniques increase available test material for selection and validation. In parallel with the southeastern research, plans are under way to extend research with the USDA-ARS research team at Lincoln, Nebraska, to develop parallel ongoing research for the upper Midwest. This will probably include establishment, management, cytogenetic, and breeding research.

In addition to production-oriented research, it has become increasingly clear that interfacing available production techniques with landowner preferences will be a critical consideration for development of the technology. Both a landowner survey and a regional case study of land and harvesting strategies will be completed during the coming year to help identify and consider the important links between herbaceous biofuels production, landowner opinions, and current agricultural systems.

ENVIRONMENTAL RESEARCH AND ANALYSIS

Background and Research Strategy

ORNL has proactively pursued the quantification of environmental implications of DFSS. Areas of evaluation include biomass production, harvest, delivery, and storage. Concerns and opportunities fall into three major categories: emissions, sustainability, and biodiversity. ORNL is pursuing collaborative inquiries with environmental

groups, business, regulatory groups, and other research institutions alike to document environmental benefits and resolve environmental issues before they become problems.

The Electric Power Research Institute, the National Wood Energy Association, the National Audubon Society, NREL, DOE, and the U.S. Environmental Protection Agency all agree that if biofuels are to contribute more than several gigajoules of energy, the use of dedicated cellulosic crops will be necessary. This may involve tens of millions of hectares of agricultural land. Consequently, much of ORNL's analysis effort is concentrated on understanding the environmental effects of energy crop deployment.

Full biomass energy fuel cycle analyses in which ORNL has participated indicate that the major environmental benefits and risks associated with energy crop production stem from agricultural land use change. The rapid development of a biomass energy industry could also lead to concerns about excessive forest harvesting, agricultural and forest residue utilization (beyond sustainable limits), energy conversion facility emissions, and water quality impacts. Analogies to biofuel systems are scarce. DFSS based on energy crops differ from both traditional agriculture and forestry practices, and cellulosic biofuel conversion facility technologies are different in many respects from pulp and paper facilities. Wood-burning utilities that already exist are a poor analogy for the more efficient biomass systems that are likely to be commercialized in the future. Comparison of the possible environmental risks of bioenergy systems with the known environmental risks of fossil fuel systems indicate that responsibly implemented biomass energy systems can offer significant benefits.

In FY 1992 and into FY 1993, ORNL has targeted research efforts in three areas.

The first addresses how energy crops may compete for agricultural land and what condition that land is in. This is necessary to understand the environmental implications of energy crops as well as cost-supply relationships. The second effort is to identify wildlife and ecosystem diversity associated with energy crop deployment. This involves the collection of field data on biodiversity of energy crops, alternative land uses, and whole landscapes. The third effort has been to develop a better grasp of energy crop sustainability and interaction of energy crops production with controversial issues such as wetlands use, forest harvesting, agrichemical movement, and valuation of environmental externalities. Because there is yet no cellulosic liquid fuels industry, ORNL has found working partners in research with utilities, agribusiness, and the forest products industry for field investigations.

Environmental Research and Analysis Highlights

Cost-supply relationships and land use change. ORNL is using its GIS and resource assessment capabilities, in collaboration with other groups, to predict where energy crops may be grown. The methodologies for analyzing energy crop cost-supply relationships were first developed by using an East Tennessee conversion facility that requires 400-dry Mg/d of wood. Land projected to be brought into energy crop production varied as a function of amount needed, hauling expenses, yields, and income from other crops. Figure 2 illustrates the relationship between biomass price, amount of land (biomass supply), and distance from the East Tennessee conversion facility. The lower the region number, the closer the land is to the facility. Net changes in percentage of cropland utilized, net change in fertilizer use, change in erosion rates,

Fig. 2. Price of delivered SRWC wood (\$\$/dry Mg at Power Plant)

and farm income were calculated from this study. One important finding was that the most-productive croplands would be converted to woody crops before less-productive croplands. The conversion of this type land, however, would result in reduced erosion and chemical use in the region closest to the power plant.

Documentation of energy crop biodiversity and landscape issues. An elaborate interagency network was established to assess bird and small mammal diversity within short-rotation wood energy crops. Although efforts are concentrated at ten sites at seven locations simulating a regional transect (Fig. 3), additional sites in Canada and the Pacific

Northwest are under study to validate the Midwest findings. Findings show that by the fourth or fifth growing season, bird diversity is greater in woody crop plantations than in pine plantations, rowcrops, pastures, hayland, and native vegetation in early successional stages. However, bird diversity is less in woody crop plantations than in mature woodland. Small mammal censuses yielded mixed results. Effects of woody crop plantations on landscape diversity appears to be most pronounced where 80 to 90% of the vegetation is in either agriculture or forests. Where more equal mixes occur, woody crop plantings do not add or detract from the landscape patterns.

Fig. 3. Additional transect of species censusing in hybrid poplar plantations.

Additional work has been directed toward plant diversity beneath energy crops. The Michigan State Long Term Ecological Research Site (LTER), the only agricultural LTER, has provided important data toward this end. Results indicate that the understory vegetation in SRWC is statistically as diverse as old field succession and no-till corn for the first 3 years. Trends in diversity, especially of shade-tolerant species, suggest that understory diversity will continue to increase during the 6- to 10-year rotation of a SRWC stand.

Assessment of energy crop sustainability. Nutrient cycling occurs to a greater extent in most energy crops than in most agricultural crops. However sustained soil nutrient availability is not well documented in these crops because of the time and expense involved in experimentation. ORNL recently completed a study that evaluated the effect of fertilizer timing on nutrient cycle efficiency in an American sycamore plantation. This study indicated very high nitrogen retention rates (no groundwater pollution), except for the one-time-only

treatment of 450 Kg/ha urea in the first year. The fertilization treatment that started at low rates and increased with tree size appeared to be most efficient. Spring and fall leaf phenology were unaffected by fertilization strategy. Of many possible nutrient stress indicators, nitrogen concentration in leaves appeared to be the most reliable, but better indicators are needed. American sycamore did not increase nitrogen concentrations in wood but tended to recycle the nutrient externally through leaf fall and root capture to attain higher productivity.

Other Environmental Issues

Because woody crops perform best on moist sites and appear capable of tolerating some amount of flooding, an interesting question arises about energy crop deployment might interact with the use of natural wetlands, farmed wetlands, and wet croplands. A draft synthesis paper has been prepared that reviews wetland types, wetland definitions, wetland functions, causes for wetlands destruction, and wetlands programs. The paper also discusses characteristics of energy crops with respect to habitats, chemical use, and land requirements and speculates on the effect energy crops would have on modifying the habitats of wet croplands. The report concludes that many wetland functions could be restored to "farmed and prior converted" wetlands by slightly modified energy crop production techniques. However, this would be problematic for landowners if their farmed or prior converted wetlands were to be reclassified and made subject to wetlands regulations. The relative value to society of potential energy crop benefits such as soil conservation, increased biodiversity, improved farm incomes, and reductions in nonpoint agricultural pollution such as fertilizer runoff deserves special attention.

Future Plans

Environmental assessment and research are areas of the program in which major expansion in work effort is needed and anticipated. As utilities and eventually biofuel conversion facilities begin to evaluate seriously the option of using cellulosic feedstocks, many questions will need to be immediately answered to facilitate the permitting process. ORNL is trying to anticipate these questions and to begin the research and assessments that will be needed to answer the questions. Environmental assessments will be conducted under the newly formed "Integrated Systems" task, whereas environmental research requiring data collection will stand alone as a separate task.

As part of the Integrated Systems task, plans are under way to use environmental risk analysis methodologies developed at ORNL to assess biomass energy systems risks. The considerable expertise available at ORNL on National Energy Policy Act (NEPA) regulations will be drawn upon to determine NEPA implications for energy crop production, handling and storage, and conversion facility siting. It is our hope that a guideline for biomass energy systems feasibility assessments, which considers the full range of economic, environmental, and social effects, can be prepared in the relatively near future.

Because the north central region and the Midwest are considered to be prime areas for energy crop deployment, three more cost-supply curves are under development in Illinois, Minnesota, and North Dakota. This will not only provide site-specific information but will allow us to determine whether cost-supply patterns will differ greatly from location to location or enough similarities exist for making broad generalizations in a region. Once the cost-supply relationship are integrated with information from field investigations and

models on biodiversity, agrichemical retention, and soil carbon, much better estimates of environmental risks and benefits can be made.

A regionwide study of energy crop supply has been initiated with the Tennessee Valley Authority for its electric service region. The study is evaluating the potential availability of wastes and residues as well as dedicated energy crops within reasonable haul distances of several facilities that may be candidates for burning biomass in combination with fossil fuels (co-firing). Preliminary data indicate that relatively large quantities of energy crops could potentially be available at less than \$50/dry Mg. Full results should be published within the next year.

The Environmental Research task will work to collect needed data. Insufficient data on fates of chemicals in energy crop systems and soil nutrient sustainability exists to predict the long-term impacts of energy crop systems. An interagency agreement with USDA's Tilth Laboratory in Iowa will initiate preliminary effort toward understanding how chemicals applied to energy crops will move through hydrologic and ecological pathways. Identifying water quality effects of energy crops is a high priority. More comprehensive efforts are anticipated in FY 1993. To address soil nutrient sustainability questions, some modest effort is being directed toward the study of belowground diversity and dynamics (soil ecology). Soil ecology may be the best single integrated indicator of ecological function, sustainability, and biodiversity.

Even if the case can be made that biomass energy systems that use dedicated energy crops produce overall benefits relative to fossil fuels systems and alternate land uses, there will still be considerable interest and concern about the environmental or ecological impacts of energy crop systems. For instance, concern

exists about the increase in nuisance species that might inhabit energy crops. These types of questions cannot be answered until large plantings exist. As large plantings begin to be established by utilities or the biofuels industry, the Environmental Research task will plan studies to document results and assist in the development of best management practices.

ECONOMIC ANALYSIS AND INTEGRATION

Background and Strategy

The Economic Analysis and Integration component seeks to ensure that all activities affecting the overall viability of biomass-based fuel cycles are understood and considered in program planning and research. This task includes the translation of research results into projections of estimated biomass production costs. Conversely, research in this task also indicates levels of production parameters that must be achieved to achieve the program cost goal.

Activities undertaken last year included starting on a project to develop energy crop supply curves for ethanol produced from corn; estimation of the energy inputs used in fertilizers and pesticides; and estimation of biomass transportation costs. Also, a synthesis study based on existing information for the Office of Technology Assessment of the U.S. Congress on biomass supplies, employment impacts, and environmental consequences; and estimation of supplies of biomass from existing forestry activities or forest resources. The goals of these activities are to estimate biomass resource availability and resource requirements (e.g., land, energy, soil erosion).

1992 Research Highlights

National supply and environmental modeling. One often asked question is how much biomass can regionally be supplied? To this question should be added at what price. A project under way in conjunction with The University of Tennessee is going to give us an answer to this question. On a regional basis, we are estimating what quantity of energy crops, and also corn, can be grown at what price. We are looking at corn because this is now the primary feedstock for ethanol production. In the future, we expect energy crops to play a larger role than corn.

The basic scheme of the modeling system is presented in Fig. 4. The Agricultural Resource Interregional Modelling System (ARIMS) is a linear programming model of crop and livestock production in the United States. As a linear program, ARIMS has the disadvantage of having fixed quantities of production regardless of the price. To deal with this shortcoming, we have linked ARIMS with an econometric model of U.S. agriculture known as POLYSIM. Inputs to ARIMS are provided from the Erosion Productivity Impact Calculator (EPIC) and Budget Planner, a model that generates crop budgets.

The purpose of this modeling system is to develop a framework that will produce price-quantity data so that simple supply curves can be estimated for biomass feedstock production and impacts on soil erosion and chemical use can be estimated. By providing enough data points, we can econometrically estimate a supply curve that, once estimated, can be used without having to run the large modeling system. Supply curves will be estimated for energy crops and corn.

CO₂ and Biomass Production

Papers were published in FY 1992 on CO₂ emissions associated with corn-to-ethanol production (Marland and Turhollow 1991) and from energy crop production (Turhollow and Perlack 1991). For corn to ethanol, about 25% of the CO₂ emissions are from producing the corn grain and 75% from fossil fuels used in the process of converting it from grain to ethanol. How the by-products from the process are treated is important in determining CO₂ emissions allocated to the ethanol. In the base case, CO₂ emissions (as C) for ethanol from corn are estimated at 16.45 kg/GJ. As a point of reference, gasoline has CO₂ emissions of 20.76 kg/GJ. The base case assumes that coal is the source of energy for the conversion process, and the CO₂ credit for the by-products is based on displacement of soybean meal on a protein equivalent basis. Net CO₂ emissions can be as low as 4.73 kg/GJ of ethanol if biomass is used as the fuel for the conversion process (Fig. 5).

Energy crops provide greater energy output per unit of energy input than corn and, hence, CO₂ output is relatively lower. Estimates of CO₂ emissions were made for a SRWC (hybrid poplar), an annual grass (sorghum), and a perennial grass (switchgrass). Standing yields (i.e., yields before accounting for all losses) are assumed to be 14, 15.8, and 13 dry Mg/ha for hybrid poplar, sorghum, and switchgrass, respectively, under current production technology. After accounting for losses, which are assumed to be 19, 16, and 31%, CO₂ emissions were 1.30, 1.84, and 1.93 kg/GJ for hybrid poplar, sorghum, and switchgrass, respectively, under current production technology. For future technology, for which we assume higher yields, lower transportation energy

Fig. 4. Modeling system used to estimate national supply and environmental impacts.

requirements, and slightly lower energy losses, CO₂ emissions are between 1.1 and 1.7 kg/GJ, significantly lower than that for fossil fuels (Fig. 6).

If the energy crops are used for electricity production, then Fig. 6 represents a fair comparison of energy crops to fossil fuels (if the fuels have equal thermal conversion efficiencies to electricity). For liquid fuels, the biomass must be processed and thermal conversion efficiency is most likely to range from about 40% today to as high as 70% in the future. CO₂ emissions from producing ethanol from energy crops with an assumed thermal conversion efficiency of 40% and no exogenous energy sources required are less than 25% those of gasoline (Fig. 7). There may also be differences in fuel efficiency between ethanol and gasoline that are not accounted for in Fig. 7.

Future Plans

The Economic Analysis and Integration task will become part of the Integrated Systems Task. During 1993 our estimation of baseline national supply, and environmental monitoring will be finished. From this, we will develop simple supply curves that can be widely used. The work with the Energy Information Administration and the Office of Technology Assessment of the U.S. Congress will be completed; from existing data we will have developed supply curves for conventional wood sources (e.g., whole tree chips, logging residues, mill residues). These are basically national-scale assessments, although there are regionalized supply curves. When commercialization occurs, it will be at a local scale.

Fig. 5. CO₂ emissions from ethanol produced from corn under varying assumptions.

Assessments must also be made at the local scale. We will undertake more site-specific analyses that will focus on impacts on the local economy, such as the impact

of a single or small number of conversion facilities on a multicounty area. Among the impacts of interest are job creation and local business activity.

Fig. 6. Comparison of CO₂ emissions from energy crops and fossil fuels.

Fig. 7. Comparison of CO₂ emissions from gasoline and ethanol produced from energy crops and corn.

ENERGY CROP DATA AND INFORMATION MANAGEMENT

INFORMATION MANAGEMENT ACTIVITIES

During this reporting period, increased emphasis was placed on information management and dissemination activities as it became apparent that formal mechanisms would be needed to retrieve the massive amount of information available at ORNL as well as to respond to an ever-increasing number of information requests. To this end, several activities were undertaken or enhanced. Personal computer-based data bases were either created or expanded to serve as repositories and analysis tools for the data and materials supplied by principal investigators. Publication of *Energy Crops Forum*, a newsletter, commenced. The extensive collection of multimedia resources was organized and catalogued, and the development of customized information packages was begun.

Since ORNL began acting as the technical manager for the DOE in 1978 for what is now the BFDP, more than 50 universities, USDA Forest Service laboratories, private individuals, and commercial organizations have funnelled information and research data to ORNL in fulfillment of contractual obligations as well as for use in regional and national assessments.

This information has been received in many different forms: numeric data reporting on research results, journal articles and reports, slides and photographs, unpublished papers and letters. In addition, the program staff has amassed a voluminous collection of materials related to all aspects of production and use of energy crops to

assist them in analyzing the results of the funded work.

In 1984, in response to the need to be able to simultaneously analyze numeric data from more than one research project at a time, the Short Rotation Woody Crops Data Base project was begun. The data base contains the location and type of field trials established with programmatic funding or co-funding, tracks actual and estimated growth and biomass yield data and cultural practices, and transforms the information previously reported in various units and styles into units of information that can easily be compared and analyzed. This data base currently has almost 14 year's worth of information for more than 300 separate data elements for more than 25 projects.

A companion effort to computerize field data in a centrally available location was begun for herbaceous energy crops projects during this reporting period. This data base will also contain the location and type of field trials, growth and biomass yield data, and cultural practices will standardize the measurement units. Although the current data base design is being reviewed, data have been entered for seven completed projects with plans to incorporate data from two additional completed projects and new switchgrass research in the near future.

These two datasets, both alone and singly, are unique in their regional and national scope. As an example of the readily retrievable data, Table 1 provides an overview of recently reported biomass data for woody and herbaceous field studies.

The principal investigators, under contract to the program and the staff at

Table 1. Recently reported energy crops yield data

State and institution	Test description	Mean annual yield (dry Mg/ha)		
		Avg	Min	Max
Woody				
Georgia	Black locust family screening trial, 2 root collar diameters, 4 cultural treatments (irrigated, nonirrigated, fertilized, nonfertilized)			
	2 years old (best yield: large root collar, fertilized and irrigated)	3.56	1.39	5.96
University of Georgia	3 years old (best yield: large root collar, fertilized and irrigated)	4.47	3.18	5.69
Minnesota, South Dakota, and Wisconsin	Hybrid poplar plantation establishment trials, 4 years old, 9 clones, 6 sites (best yield: DN-34 at Mondovi, Wisconsin)	4.3	2.02	8.29
U.S. Forest Service, North Center Experiment Station	Hybrid poplar plantation establishment trials, 5 years old, 11 clones, 6 sites (best yield: NE-54 at Milaca, Minnesota)	3.67	0.90	6.94
Washington	Alder spacing trial, 5 years old, 3 spacings, 2 irrigation levels (best yield: 0.5 spacing, high irrigation, and fertilization)	6.08	3.46	9.72
U.S. Forest Service, Pacific Northwest Experiment Station	Hybrid poplar clonal trial, 5 years old, 3 spacings			
	Dula 01 (little or no difference exhibited at 0.5- and 1.0-m spacings)	9.98	8.12	10.96
	Hybrid 11 (little or no difference exhibited at 0.5 and 1.0 m spacings)	17.64	15.64	18.80

Table 1 (continued)

State and institution	Test description	Mean annual yield (dry Mg/ha)		
		Avg	Min	Max
Herbaceous				
Alabama	Genotype/variety trial, 4 years old, 8 genotypes, 12 species (best yield from Alamo switchgrass)	14.49	9.99	28.26
Auburn University	Species screening trial, 6 years old, 2 species (best yield from hybrid energy cane)	17.27	6.10	25.60
Iowa Iowa State University	Species screening trial, 4 years old, 8 species (best yield from sweet sorghum)	22.15	4.90	20.20
Kentucky University of Kentucky	Species trial, 4 years old, 6 fertilizer levels (best yield from tall fescue)	7.52	4.31	10.28
	Genotype test, 4 years old, 4 species (best yield from carthage switchgrass)	17.19	12.50	22.00
Indiana Purdue University	Species trial, 3 years old, 8 species, 3 fertilizer levels (best yield from switchgrass)	16.04	8.67	15.92
New York Cornell University	Species screening trial, mixed root ages (mostly 3-year old stand), 9 species or mixtures, 3 fertilizer levels (best yield from flat pea)	9.37	3.05	13.14
North Dakota North Dakota State University	Species screening trial, mixed root ages, 13 species or mixtures (best yield from forage sorghum)	16.73	2.10	18.30
Ohio Geophyta	Species screening trial, 5 years old, 8 species or mixtures, (best yield from mixture of rye and sorghum x sudangrass)	14.11	4.10	23.10
Virginia Virginia Polytechnic Institute and State University	Fertilization level trial, 5 years old, 7 fertilizer levels, (best yield from switchgrass)	9.28	4.40	12.00

ORNL, have been extremely prolific writers, resulting in more than 2000 reports, journal articles, papers, theses, and dissertations. In 1988, a bibliographic data base was created to index these materials for two reasons to ensure accessibility and to document program activities. Additional books, reports, conference proceedings, and reprints have also been collected to support in-house analyses and assessments. During this reporting period, a graduate student in library science from The University of Tennessee designed a subject category shelving system for this exceptional collection of materials, as well as creating another bibliographic data base. Recently, the two data bases were combined, resulting in a file with more than 3500 keyworded entries that will be the cornerstone for an all-inclusive update to a bibliography originally published in 1989.

Because ORNL is recognized as the premier authority on feedstock production issues, there are frequent requests for information. Not only is the bibliographic data base searched on an almost daily basis to identify and retrieve relevant materials, as is the 2700 record data base of slides and photographs that illustrate programmatic achievements. Work has just been initiated on the creation of subject-specific information packages composed of

relevant reprints and reports, which will facilitate quick response to the numerous information requests.

In the early part of 1991, a decision was made to begin publishing a newsletter. The objectives were to (1) facilitate communication and an awareness of ongoing research among the research community, (2) transfer research results to those outside the research community, and (3) identify and develop a constituency for energy crops research. Initial efforts consisted of the identification of members of the target audience, which was defined as an international community of researchers in academia, government organizations and private industry, policy and decisionmakers at all levels of government, private citizens, public interest groups, and media contacts. The first issue of *Energy Crops Forum*, published in the fall of 1992, was sent to approximately 1200 people. The reaction to the newsletter exceeded all expectations, with almost 75% of the original recipients indicating a desire to continue receiving it as well as yielding more than 300 additional subscriber names. Referrals by current recipients and citations in other publications resulted in additional subscribers. The distribution list is hovering just beneath the 2000 level, and new subscription requests are being received almost daily.

FUTURE DIRECTIONS

Research, development, and demonstration of dedicated feedstock supply systems is needed at a much broader scale than is currently planned by ORNL's BFDP. For the past 14 years, BFDP has been developing a technology for a future in which large amounts of biofuels are desired for energy self-sufficiency, global carbon mitigation, and rural economic enhancement. That future is approaching rapidly. There is a need to apply the knowledge already gained to demonstrate that our vision of significant contribution of biofuels to the U.S. economy can be a reality. This demands that a near-term integration and demonstration effort be added to ongoing long-term research and development activities.

The near-term research needs can best be understood by considering the efforts needed to facilitate commercial success at a single-facility level. The question currently being asked by both federal funding agencies and private sector investors is "what locations offer the greatest opportunity for success with the current technology?" Integrated systems assessments could answer this question. Such assessments are required so that the complex interactions between and among energy markets, energy crops and cropping systems, the environment, economics, supply logistics, National Environmental Policy Act requirements, agricultural programs, and energy policies can be defined and evaluated. The newly planned Integrated Systems task within BFDP will include such activities as GIS analysis; complete fuel cycle analysis; economic, environmental, and sociological impact studies; landscape modeling; national and regional cost-supply modeling; tax effect

studies; CO₂ assessments; and nonmarket benefit valuations. Some of these activities will be conducted by cooperating in feasibility studies for specific studies, whereas others will be more generic. The combined knowledge provided by these assessments will provide the ORNL staff with a holistic understanding of biomass energy systems that can be used to guide the development of commercial projects both in the United States and internationally.

Assuming that one or more specific sites are selected for federally funded scale-ups or demonstrations of integrated biomass energy systems that use dedicated biomass feedstocks, energy crop technologies previously developed for the general region will need to be adapted to the specific site. It will be important to synthesize energy crop information already available for the general region into "how-to" guides specifically designed to assist farmers and industry in making decisions on which and what levels of energy crops to produce. Demonstration plantings should be established, and extension efforts should be initiated through traditional farmer's networks and information resources. Organization of field days to demonstrate planting and management techniques will be important. The best available tree seedling and/or herbaceous crop seed mixtures will need to be made available to local nurseries or seed producers to begin the process of multiplying the best available materials. Demonstrations will have the greatest likelihood for success if expertise on energy crop production (developed by previous BFDP-funded research) is already available in the region. Although it may be reasonable for ORNL staff to be

involved in the development of one or two specific projects, the role of ORNL staff is anticipated normally to be that of advisors and providers of general information to local project developers. The ability of BFDP to fund site-specific demonstration activities will be severely limited at current budget levels. BFDP will be seeking ways to participate in such demonstrations, however, so that environmental data can be collected and used for environmental impact analysis and for designing more environmentally sound biomass energy systems.

To maintain a program with a national and long-term focus, technology development strategy is needed that is diverse and broad in its approach. A critical element is developing additional energy crops and cropping systems for several regions of the country. The crops and cropping technology available today simply will not supply the amounts of biomass desired at the costs desired on the national scale. New crops will be needed to suit different soil types, to reduce risks, to optimize environmental benefits, to more effectively utilize farm labor, and to provide feedstocks in areas with serious climate and/or soil limitation. Along with the development and genetic improvement of new crops, research on the ecology of the crops and cropping systems needs to be expanded to ensure the development and implementation of environmentally sound production techniques. Because the development of new crops and environmentally sound cropping systems is a long-term process, it cannot be delayed. This is a large effort that could and should be shared by both USDA and DOE and as many state, local, and private research organizations as possible. BFDP's crop development task will focus on just a few crops so that the value of crop development efforts can be more quickly demonstrated. Likewise, the environmental research task will limit its

evaluations to (1) those locations and cropping systems with a high probability of relatively near-term commercial potential and/or (2) existing commercial plantings.

To the extent that reducing the risks, both biological and economic, of producing large acreages of energy crops will become more and more important as more acres are planted, basic biological research on energy crops will be necessary to support the emerging industry. Integrated breeding, biotechnology, and physiological research on selected energy crops will provide both crop-specific information and new methodologies and tools for addressing problems associated with pests, diseases, droughts, and other climatic stresses. This is also a large effort that is expected to need and utilize the resources of many different research groups. ORNL's BFDP anticipates supporting this type of effort only in conjunction with crop improvement research.

The development of biomass energy on a large scale both demands and justifies the development of specialized harvesting and handling equipment. Reduction of harvest and handling system costs will be critically important to making the prices of dedicated feedstocks competitive with other sources of energy. It will be necessary for the research community to define the equipment specification, to conduct sufficient engineering systems analysis to clearly define the systems conditions under which the equipment should be expected to operate, and to identify the potential market. Private industry, however, is expected to play a large role in actual equipment production and testing.

Both near-term and long-term research and implementation activities can be enhanced by ensuring that information already available is put in the hands of the people who need it. ORNL has a tremendous resource of materials on energy crop technology produced through

research contracts and gathered by program staff over the past 14 years. This material needs to be made more accessible to potential users through efficient information management and value-added information synthesis products. BFDP has begun serious efforts to effectively manage biomass energy systems information and to generate useful information products. Cooperative efforts with NREL are being initiated so that the information can be presented with a complete biomass energy systems focus.

ORNL has unique expertise in the biomass energy arena as a result of the experiences acquired by its BFDP program managers. Four members of the staff have been with the program for more than 10 years, and most have been associated

with the program for more than 5 years. Consequently, most members of the BFDP staff are in constant demand for giving presentations to local, state, national, and international groups; reviewing papers and proposals; participating in planning meetings and national roundtables; and giving advice to individuals and groups in the private sector. These activities are presumed to be valuable to DOE and will be continued to the extent possible. However, such activities are not always compatible with efficient and effective management of a diverse research program with projects located across the nation. ORNL will strive to seek an appropriate balance between technology transfer and research management activities within the funding limits available.

APPENDIX A

**BIOFUELS FEEDSTOCK DEVELOPMENT
PROGRAM PROJECTS**

Table A-1. Biofuels Feedstock Development Program projects

Institution	Investigator	Title
Amana Society ^a	L. G. Gnewikow D. Shoup	Monoculture Viability Trial of Woody Crops for Energy Production
Auburn University	J. A. Mosjidis	Variability for Biomass Production and Plant Composition in <i>Sericea Lespedeza</i> Germ Plasm
Auburn University	D. I. Bransby	Selection and Improvement of Herbaceous Energy Crops for the Southeastern USA Biomass Energy Strategies for Carbon Dioxide Mitigation in the United States
Auburn University	D. I. Bransby	Development of Optimal Establishment and Cultural Practices for Switchgrass
Iowa State University	R. B. Hall E. R. Hart H. S. McNabb, Jr. R. C. Schultz	Selection and Breeding of Pest-Resistant Clones of <i>Populus</i> for Biomass Energy Production in the North Central Region
Iowa State University	I. C. Anderson D. R. Buxton C. S. Accola	Selection of Herbaceous Energy Crops for Production in Double Cropping Systems
Michigan State University	D. I. Dickmann K. S. Pregitzer	Net Assimilation and Photosynthate Allocation of SRIC <i>Populus</i> Clones
Mississippi Agricultural & Forestry Experiment Station	S. B. Land	Early Selection Criteria and Clonal Propagation Methods for Increased Productivity of Sycamore in Short-Rotation Energy Systems
North Dakota State University	D. W. Meyer D. O. Erickson R. G. Johnson	Evaluation of Herbaceous Biomass Crops in the Northern Great Plains
Oak Ridge National Laboratory	H. Van Miegroet R. J. Norby	Optimum Nitrogen Nutrition in Short-Rotation Sycamore Plantations
Oak Ridge National Laboratory	J. W. Ranney	Environmental Planning and Analysis
Oak Ridge National Laboratory	S. D. Wullschleger	Switchgrass Physiological Development for the Southeast

Table A-1 (continued)

Institution	Investigator	Title
Oak Ridge National Laboratory	G. A. Tuskan T. J. Tschaplinski	Improvement of Energy Crop Responses to Drought Stress
Oklahoma State University	C. G. Tauer	Preserving <i>Populus</i> Germ Plasm for Breeding Programs
Oklahoma State University	C. M. Taliaferro	Breeding and Selection of New Switchgrass Varieties for Increased Biomass Production
Purdue University	K. D. Johnson	Evaluation of Potential Herbaceous Biomass Crops on Marginal Land
Southern Illinois University	W. C. Ashby J. E. Preece P. L. Roth	Genetic Biomass and Growth Analysis of Clonal Silver Maple (<i>Acer saccharinum</i> L.) in Several Locations
State University of New York	E. H. White	Bioenergy from Willow
Texas A&M University	M. A. Sanderson	Evaluation of Switchgrass Cultivars and Cultural Methods in the South Central U.S.
Tuskegee University	A. Weaver	Biomass Research and Training Program
University of Georgia	B. C. Bongarten S. Merkle M. Crump	Optimizing Energy Yields in Black Locust Through Genetic Selection
University of Georgia	P. L. Raymer	U.S. 1992 Rapeseed Variety Trials
University of Idaho	K. A. Mahler	Development of Broadly Adapted Cultivars of Winter Rapeseed as a Source of Diesel Fuel
University of Kentucky	M. Collins	Biomass Production by Fescue and Switchgrass Alone and in Mixed Swards with Legumes
The University of Tennessee	B. C. English	Subregional Cost Supply Studies and Economic and Technical Analyses
The University of Tennessee	B. C. English M. G. Bhat	Synthesis of Energy Crop Potential
The University of Tennessee	B. C. English	Economic and Technical Analyses

Table A-1 (continued)

Institution	Investigator	Title
The University of Tennessee	S. E. Schlarbaum	Black Locust Provenance Data Collection and Analysis
University of Washington	R. F. Stettler P. E. Heilman T. M. Hinckley H. D. Bradshaw, Jr.	Genetic Improvement and Evaluation of Black Cottonwood for Short-Rotation Biomass Production
USDA Agricultural Research Service	K. P. Vogel	Genetic Variation Among Switchgrasses
USDA Forest Service North Central Forest Experiment Station	J. G. Isebrands B. E. Haissig	Increasing Yields of Poplar Energy Plantations
USDA Forest Service North Central Forest Experiment Station	E. A. Hansen D. Netzer	Short-Rotation Woody Crop Trials for Energy Production in the North Central United States
USDA Forest Service Pacific Northwest Research Station	D. S. DeBell C. A. Harrington G. W. Clendenen	Increasing the Productivity of Biomass Plantations of Alder and Cottonwood in the Pacific Northwest
Virginia Polytechnic Institute and State University	D. J. Parrish D. D. Wolf W. L. Daniels	Switchgrass as a Biofuels Crop for the Upper Southeast

^aOther institutions cost sharing the Amana Society contract include Iowa State University, the Iowa Department of Natural Resources (DNR) Energy and Geological Resources Division, and the Iowa DNR Forestry Division.

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