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RESEARCH TO DEVELOP IMPROVED PRODUCTION METHODS FOR WOODY AND HERBACEOUS BIOMASS CROPS

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Abstract

The Department of Energy's (DOE's) Biofuels Feedstock Development Program (BFDP) has led the nation in developing short-rotation woody crops (SRWC) and herbaceous energy crops (HEC) as feedstocks for renewable energy. Over the past 15 years, the BFDP has examined the performance of 154 woody species and 35 herbaceous species in field trials across the U.S. It has managed research projects involving more than 100 federal, university, and private research institutions. One result of this effort to date has been the prescription of silvicultural systems for hybrid poplars and hybrid willows and agricultural systems for switchgrass. Selected clones of woody species are producing dry weight yields in research plots on agricultural land that are 3 to 7 times greater than those obtained from mixed species stands on forest land, and at least 2 times the yields of southern plantation pines. Selected switchgrass varieties are producing dry weight yields 2 to 7 times greater than average forage grass yields on similar sites. Crop development research is continuing efforts to translate this potential, in a sustainable manner, to larger, more geographically diverse acreage. Research on environmental aspects of biomass crop production are aimed at developing sustainable systems that will contribute to the biodiversity of agricultural landscapes. Systems integration aims to understand all factors affecting bringing the crop to market. Factors affecting price and potential supplies of biomass crops are being evaluated at regional and national scales. Scale-up studies, feasibility analysis and demonstrations are establishing actual costs and facilitating the commercialization of integrated biomass systems. Information management and dissemination activities are facilitating the communication of results among a community of researchers, policymakers, and potential users and producers of energy crops.

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Introduction

The U.S. Department of Energy (DOE) has supported a national research program on biomass production for energy since 1978. Broadly stated, the mission of the DOE Biofuels Feedstock Development Program (BFDP) is to provide leadership in developing and demonstrating environmentally acceptable and commercially viable biomass supply systems. The mission is being pursued in a way that (1) integrates and promotes multiple objectives for agriculture, energy and the environment; (2) seeks and fosters the best research, development, and demonstration in the private, academic and government sectors; and (3) ensures information on biomass supply systems is accurate, understandable, and accessible. This mission has been undertaken to insure (1) new, profitable and environmentally acceptable cropping options for biomass producers; (2) secure, affordable and sustainable supplies for biomass end-users; and (3) that up to 15% of the U.S. primary energy demand can be met from biomass. The BFDP is managed by the Environmental Sciences Division of Oak Ridge National Laboratory (ORNL), Oak Ridge, Tennessee.

Related to the BFDP mission are the issues of domestic energy security, rural job creation, CO_2 mitigation, and global warming. Renewable energy from biomass creates the potential to favorably influence each of these issues. The intent of the BFDP is to develop technologies that can be a major contributor to achieving or exceeding EPAct requirements (Section 502) of producing sufficient domestic replacement fuels to substitute, on an energy equivalent basis, 10% by 2000 and 30% by 2010 of the project consumption of motor fuel by light duty vehicles in the U.S. (DOE, 1994). This would require a feedstock supply of between 190 and 527 million tons per year of raw lignocellulosic biomass, depending on the efficiency of converting the feedstock to transportation fuels. Initially the production will be based on waste lignocellulosics from agricultural, the wood products industry, and muncipal refuse. Is it estimated that there may be 219 million tons of economically recoverable but unused wastes. Thus to meet the 2010 EPAct requirements another 200 to 300 millions tons of dedicated biomass crops may be required. It has been projected that this level of production could theoretically be met on around 12 million ha of cropland at prices less than $2.00/Gigijoules (GJ) by 2005 with modification of USDA farm policies and programs to facilitate biomass crop production and continued support of research and demonstration at a level of about $20 million per year. It is also assumed there would be significant cost sharing on the R&D from the private sector.

The markets for dedicated biomass crops do not exist today, whether the product be biomass power through direct combustion or gasification, or liquid transportation fuels through thermochemical or biochemical conversion of cellulose. There are co-product based examples of renewable biomass energy which account for 3-4 GJ of energy output annually; although these examples rely on residues and wastes from agriculture and the forest products industry and to a small degree corn starch to ethanol. The BFDP strives to not only assure that the dedicated biomass crop technologies are available when and where needed, but also that the infrastructure for production and

delivery of the biomass supplies is also developed in tandem. There are five major task areas of the program that support this goal.

Short-Rotation Woody Crop Research

The BFDP has the objective of developing and refining short-rotation woody crop (SRWC) silviculture systems for the production of reliable, low-cost, high quality, sustainable wood for fuel and fiber in the U.S. This task includes the development of equipment systems for improving the efficiency and reducing the cost of producing and harvesting SRWC.

Over the past 15 years the BFDP has supported woody crop research integrating traditional breeding, silvicultural research, and molecular genetics throughout the U.S. In the Pacific Northwest, a well integrated research effort has led to the development of high-yielding (ca. 18 to 26 dry Mg ha^{-1} yr^{-1}) hybrid poplar cultivars adapted to the edaphic, climatic and biological constraints of the region (Wright, 1994). These material are now being planted on over 20,000 hectares with more than double that amount anticipated to be planted within the next 5 years. The progress in yield improvement has not been as dramatic in other parts of the U.S., although much has been learned about silvicultural management of the crops. Nevertheless age 7 yields of the best clones are approaching 12 dry Mg ha^{-1} yr^{-1} in scale-up clone-site trial and up to 18 dry Mg ha^{-1} yr^{-1} in small plots in the North Central Region.

The BFDP is gradually modifying and linking the ongoing research funded at several institutions to create regional woody crop development centers for the North Central Region, the South and the Northeast that are modeled after the successfully integrated efforts in the Pacific Northwest. Each center will optimally involve at a minimum, the integration of silviculture, genetics, plant breeding, entomology and pathology. To the extent possible, new and ongoing research dealing with mechanization and harvesting, economic analysis, environmental studies and demonstrations will be linked with the regional crop development centers as well.

The principal effort of the three regional crop development centers is the selection and breeding of new hybrid poplar plant materials for SRWC production. In the North Central Region, the Iowa State University manages the genetic improvement of hybrid poplar in collaboration with 3 universities, and 2 U.S. Department of Agriculture (USDA) Forest Service Research Stations. Several nurseries and paper companies are contributing to this effort through participation in the North-central hybrid poplar Research Consortium. In the southern part of the U.S., the Mississippi State University is initiating breeding work on hybrid poplar in collaboration with 2 other universities and the USDA Forest Service. Although a consortium has not yet been formally established, 6 paper companies have agreed to assist with germplasm collections, and 3 companies are scheduled to assist with regional trials when new

clonal material is produced. In the Northeast, the State University of New York, in close association with the University of Toronto in Canada, is serving as the focal point for the evaluation of willow hybrids in the U.S. Several private companies, primarily utilities, are contributing funds, manpower and lands to support trials of new willow clones. In the Pacific Northwest, a very well integrated effort continues with cooperation between 3 universities and a large number of companies. Now that breeding for the Pacific Northwest is being done by private companies, the University of Washington (UW) is serving as the focal point for the *Populus* Genetic Mapping Cooperative. A closely linked effort is the *Populus* Genetic Transformation Cooperative managed by Oregon State University. Both these efforts transcend the region and have national applicability for all hybrid poplar work. Details of some of the work ongoing at each of these centers was recently described by Tschaplinski and Wright (1994).

To assure that woody crop development centers produce materials that have commercial value, the programs are including the establishment of regional yield and site-adaptability trials of selected genotypes. Here, (1) productivity estimates are being verified on a per unit area basis, (2) adaptability over a broad geographic area is being established, (3) climate-site factors are being evaluated in terms of their impact on pest resistance, and finally (4) technology is being transferred from the research center to subregions where landowners/producers who will be growing the crops can gain "hands on experience" with new production systems. Four regional test sites are ongoing or planned for the North Central Region. Optimally designed tests will evaluate 30-50 new, selected clones per year, planted in large monoclonal blocks over a five-year period. From these tests it is likely that a single highly productive, regionally adapted, pest resistant clone will be identified each year following the initial five years of growth. Results from these efforts will allow better species-site matching and improved productivity estimates from each site (Downing and Tuskan,1995).

Herbaceous Energy Crop Research

The goal of herbaceous energy crop (HEC) research is to develop crops that can be economically produced on a wide variety of sites and readily and practically incorporated into conventional farming operations. Systematic screening studies in a variety of locations have shown that switchgrass can meet this goal for several regions of the U.S. While other species may also be viable candidates, switchgrass has been chosen as the model herbaceous energy crop species for demonstrating the concept. It has a geographical range that covers most of the United States and portions of Canada and Central America and is found in diverse habitats ranging from Midwestern prairies to brackish marshes and open woods. The grass can be used both as a biofuel and as a forage species (although optimal characteristics for each use differ). Switchgrass has several positive environmental attributes including low nutrient use, low pesticide requirements, and a perennial growth habit (McLaughlin, 1994)

Screening studies continue to be used to identify the most promising cultivars and cultural practices. Selected varieties have been utilized in a switchgrass breeding program to further improve production potential. Breeding studies are being integrated with physiological evaluations to develop physiologically based selection criteria for improving yield and identifying promising parents. Classical breeding techniques are being used for rapid improvement of existing varieties with the most desirable phenological and physiological attributes. Tissue culture techniques are being developed to augment classical breeding efforts.

There are currently seven actively funded projects in the herbaceous species task. Six of the projects located in the Southeastern region of the U.S. are collaborating to develop the management techniques, physiological understanding, and breeding technology to establish, produce and harvest switchgrass in an economically and environmentally sound manner. The six projects incorporate production research and regional variety trials at three locations, Texas A&M, Virginia Polytechnic Institute and Auburn University; breeding research at Oklahoma State University; development of techniques to propagate and screen switchgrass through tissue culture techniques at the University of Tennessee; and physiological characterization of switchgrass at ORNL. With ORNL staff facilitating the linkages between the investigators at the different institutions, the set of projects meets the program's objective for having a switchgrass crop development center for the South.

Recent third year results from the variety trials, which are established in Alabama, Texas, Virginia, Tennessee, Kentucky and West Virginia indicate that the select varieties are capable of producing high yields on a variety of site types (McLaughlin, personal communication, May 1995, ORNL). In the third year of growth, average yields of the best varieties ranged from 15.2 to 16.8 dry Mg/ha in 1994 over 19 different locations. Maximum yields of the best varieties ranged from 20.1 to 27.6 dry Mg/ha in 1994. Average yields of all nine of the varieties established in the trials are also good, ranging from 12 to 16.3 dry Mg/ha. Harvesting frequency studies are showing that a double cut system produces highest yields in Alabama and Virginia while a single cut system is best in Texas. The timing of the second cut is very important. Breeding research has gone through 3 cycles with selected plants averaging 60% above non-selected plants. The highest yielding variety continues to be Alamo. Switchgrass is being successfully tissue cultured from nodes, leaves, seeds and florets. Four varieties have been placed in tissue culture. Yields from tissue cultured Alamo varieties established in experimental trials Tennessee have been very high with 1994 yields averaging 22.5 dry Mg/ha and a maximum plot yield of 36.5 dry Mg/ha.

Work in the North Central region is presently limited to a collaborative effort with the USDA Agricultural Research Service at Lincoln Nebraska. The project is conducting yield trials of northern cultivars of switchgrass, evaluating fertilization effects and new herbicides and beginning a breeding effort. If additional money becomes available, switchgrass work in the North Central region would be expanded. A workshop for

potential collaborators and stakeholders has been conducted in an effort to define the need and interest in additional switchgrass work in the region.

Environmental Research

The objective of BFDP's environmental research is to develop site-specific regional data related to environmental parameters such as biodiversity, chemical fate, soil chemistry and carbon content, erosion and surface water runoff, and plantation design which would facilitate the implementation of SRWC plantings at the field, landscape, and regional levels as to ensure sustainable, environmentally acceptable feedstock production.

Since the beginning of the BFDP, environmental acceptability and sustainability have been part of the selection criteria for identification of promising crops and production systems. Perennial crops have been favored over annual crops because of their ability to provide soil stability, nutrient retention, and reduced agrochemical requirements. Tree crops with 5-10 year rotations have been favored over very short 1-3 year rotations, in part, to reduce nutrient drainage from soils and the potential for soil compaction effects from frequent harvesting. Fertilization studies designed to consider effects on water quality have demonstrated that application procedures can minimize water quality impacts and provide more cost-effective impacts on growth if applied on an as needed basis during the rotation rather than in a large initial application (Van Miegroet *et al*, 1994). Bird and small mammal surveys have been conducted in commercial and experimental plots to address biodiversity compared to traditional land uses. Results from some of these studies have shown switchgrass plantings can serve as habitat for some Prairie songbirds which are dwindling in population numbers and that woody crop plantations established next to forestland allow internal forest species to extend their habitat range to the edge of the forested area (Tolbert and Downing, 1995). Where woody crops provide the only wood cover in a farm area, preliminary data suggests they will be used by a variety of birds.

Existing and proposed biomass plantings at demonstration and industrial sites are providing the opportunity to expand the existing data needed to address environmental questions associated with biodiversity, chemical fate, erosion and surface water movement, and soil chemistry in a number of regions with the potential for biomass crop production (Tolbert and Downing, 1995). A small scale study is underway with the National Audubon Society to monitor groundwater drawdown beneath demonstration hybrid poplar plantings in Minnesota, because of concerns about potential effects on nearby wetlands. Comparisons of large-scale plantings with adjacent or nearby natural areas, wetlands, managed forests, grasslands, and agricultural sites will provide data to determine if location of biomass crops can enhance the biodiversity of existing landscapes. Some flexibility will exist to design experimental SRWC plantings to fit within existing landscape features to address the

premise that plantation design and silvicultural options can enhance SRWC value for wildlife. Contingent on program funding levels, plans include monitoring various SRWC management options such as interplanting trees with a cover crop, planting specific tree or cover crops adjacent to SRWC plantations, and planting multiple commercial species to determine if SRWC can increase biodiversity.

The fate of chemicals, including pesticides, herbicides, and fertilizers, are an important component of developing environmentally acceptable biomass crop systems. There are currently no field data specific to biomass crops which addresses how environmental parameters such as soil type, species, cover crops, or climate influence movement of chemicals within the soil and the release of chemicals into soils and groundwater. The effect of these physical parameters on the type and quantity of chemicals which migrate from production sites and their ultimate effects on surface water quality are also unknown. The BFDP is currently examining some water quality issues using small watershed models in collaboration with Purdue University. Collaborative work initiated in fall 1994 with the Tennessee Valley Authority in northern Mississippi, western Tennessee and northern Alabama (with Alabama A&M involved) will assess the fate of chemicals applied to SRWC with and without a cover crop, switchgrass, and corn plantings. Studies in Minnesota which were initiated in 1994 involving the USDA Forest Service and the University of Minnesota are looking at nutrients, pesticides and herbicides in soil and groundwater. Additional field studies, preferably linked with each woody and herbaceous crop development center, are needed to estimate the above parameters under the wide variety of physical boundaries within and among regions.

The third area of environmental research is the sequestration of carbon in soils by biomass crops. Carbon sequestration in soil has been predicted to be an important means of reducing greenhouse gases. Assessing soil carbon changes is essential in developing greenhouse gas balances and determining the economic importance of potential carbon sequestration tax credits. Studies on CRP sites planted to switchgrass have shown that soil carbon sequestration may be as much as 1 Mt C/ha/year over the first 5 years in the top 100 cm of soil (McLaughlin, 1994). New studies collecting soil chemistry data at multiple sites in different regions will provide information on potential differences in soil carbon sequestration rates as a function of soil type, tree or grass species, management systems, harvesting regimes, and climate. The results of soil carbon studies can contribute to consideration of issues related to carbon tax credits.

The BFDP's Environmental Task is attempting to provide a well-documented, technically sound data base on environmental impacts of various silvicultural options. This information can then be used on a region, site, and species basis to document the sustainability and environmental benefits of energy crops as currently envisioned. These data will also provide a baseline and basis for improving the cultural systems to enhance the sustainability of energy crops. It is anticipated that with adequate funding at least five years will be required to adequately quantify changes in soil carbon,

chemical composition of groundwater and surface water runoff, and biodiversity associated with representative energy crop sites in the U.S.

Systems Integration and Analysis

The objective of the Systems Integration and Analysis task is to assess the environmental and economic costs, benefits, and trade-offs associated with various SRWC silviculture systems for life cycle analysis and to determine carbon offset and carbon credits from SRWC that would allow trading and/or purchase of such credits.

Economic analyses of SRWC production systems have been a part of the BFDP program since program inception and have become increasingly sophisticated as our understanding of SRWC production technology has matured. Preliminary evaluations analyzed the variation in production costs with respect to resource characteristics and economic conditions and examined the nature of potential trade-offs in system design and operation. Some of the early studies were concerned with determining optimal rotations, yield-response to fertilization, and whether certain management options, such as irrigation, were likely to be cost-effective. As better SRWC information and data became available, these studies were refined and new studies undertaken to look at SRWC economics more from the perspective of potential developers. Farm level studies were conducted (English *et al* 1991) and preliminary regional supply curves estimated (Graham and Downing, 1995). Fuel cycle studies and assessments of carbon flows from SRWC plantings were also undertaken (Perlack *et al,* 1992). Recently a complete accounting of hybrid poplar and switchgrass production costs has been documented, though not yet published.

Several attempts have been made to estimate the potential supplies of biomass crops that could be available on a national scale at prices that would provide the landowners a profit and yet be feasible for use as an energy feedstock. The most comprehensive effort has been undertaken in collaboration with USDA, Environmental Protection Agency, and the Office of Science and Technology Policy. Results are being reported by others at this conference (Roningen et. al., 1995), but the bottom line is that if energy useres could pay $2.00 GJ, then energy crops could be competitive on about 12 million hectares. However, with coal available at less than $1.25 GJ, the supplies of biomass crops that could be competitive with coal, using conventional conversion technologies are very limited. Work is currently also underway to examine in a more detailed level the potential supplies of biomass crops that would be available in 11 selected Midwestern and southern states. Environmental and economic drivers are being linked in the analysis efforts.

Scale-up, Feasibility and Demonstration

The goal of this task is to facilitate commercialization of integrated biomass energy systems. The objectives of this task are to gather, assess, and disseminate information on operational costs, requirements, risk and other considerations in planting and developing entire integrated commercial supply systems of biomass crops. The task extends energy crop research results to successively larger planting blocks from 30 to 300 acres; 1000 acres at a time. A major component of the task involves synthesizing relevant information from herbaceous and woody crop development, environmental research, and systems integration and analysis components of the BFDP and making it available to industries developing or considering biomass facilities.

The BFDP is supporting one major scale-up project, a hybrid poplar project administered by the WesMin RC&D near Alexandria, Minnesota. One thousand acres were planted in late May 1994 following early spring land preparation. All land was enrolled in the Conservation Reserve Program (CRP) and qualified for 5-year contract extensions. Seven hundred thousand hybrid poplar cuttings were produced and planted by several private nurseries. Some plantings were successful and have been replanted this spring along with an additional 1000 acres. Lessons learned by the participants included the importance of fall site preparation, site selection, specifications for planting stock, and the importance of good nursery management of the planting stock. Valuable information on costs, labor and issues highlighted by the experience are being summarized in a document soon to be available to the public (Downing *et al*, 1995). Some of that information is summarized in the presentation by Kroll and Downing (1995).

The BFDP is working with industries and landowners considering electricity and liquid fuel produced from biomass by participating in 10 DOE-funded feasibility studies entitled "Economic Development through Biomass Systems Integration". The benefits expected to accrue to the DOE biomass programs are an increased understanding of how potential users of energy crops expect to evaluate dedicated feedstock supply systems and the kinds of information needed for the operational phase. The BFDP participation adds an agricultural perspective to the feasibility study groups and provides access to results of energy crop research performed for the BFDP since 1978.

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