BIOMASS FEEDSTOCK RESEARCH AND DEVELOPMENT FOR MULTIPLE PRODUCTS IN THE UNITED STATES

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ABSTRACT: A recent presidential Executive Order to triple current levels of bioenergy and biobased production by 2010 has increased interest in determining whether sufficient biomass resources will be economically available to support the goal. The United States has a well-structured program of research and development which is focusing on increasing potential energy crop and crop residue availability under economically and environmentally sustainable conditions. Genetic improvement programs are ongoing in three U. S. locations for hybrid poplar and cottonwood, in one location for willow, and in four locations for switchgrass. Variety testing and cropping systems development is being conducted at wider variety of sites for all three crops. Molecular genetics is providing important information and tools for identifying and controlling desired traits. The program is also expanding to address supply logistics issues for both energy crop and residues. Equilibruim model analysis performed jointly with the U.S. Department of Agriculture suggests that at farmgate prices of about $33 dt and $44 dt, between 7 and 17 million ha of land could convert to energy crop production without negatively affecting food supplies. Large amounts of crop residue also become profitable for farmers to collect at similar prices. This potential for supporting significant bioenergy and biobased products industries in the United States will only be realized if the environmental and economic values to local communities are recognized and factored into energy and environmental policy.

1. INTRODUCTION AND BACKGROUND

Currently about 1.5 exajoules of heat, power and fuels is produced from about 3 exajoules of primary energy in the form of biomass in the United States The biomass used includes urban wood wastes, industry residues, forest residues, black liquor from the paper pulping process, and grains used for ethanol. Tripling primary energy inputs will require greater use of urban, industry, and agricultural residues, and the production of dedicated energy crops. Increases in conversion efficiencies could reduce the amount of feedstocks needed to achieve a tripling. Strategies for achieving the tripling are under discussion, and policy actions are under consideration withing both the federal government and by state governments. Green power offerings by the private sector are increasing though the acceptability of some biomass options is still under debate. There is strong bi-partisan support for aiding the farm economy, which is under severe stress.

This paper will focus on summarizing recent research and analysis devoted to expanding economically viable and environmentally beneficial biomass resources in the United States. The work, supported by the U.S. Department of Energy's Office of Transportation Technologies and Office of Power Technologies, was performed by the Bioenergy Feedstock Development Program (BFDP).

2. BIORESOURCE DEVELOPMENT

The BFDP has focused the majority of its resources on developing energy crops to support a substantial bioenergy and/or bioproducts industry in the United States. Crop screening studies in the 1980s identified several promising species. Three model species with contrasting management systems were chosen for further development. These include hybrid poplars and cottonwoods grown as single stem trees and 5- to 10-year rotation management systems; willows and hybrid poplars grown as coppice trees in more tightly spaced, 3- to 5-year rotation management systems, and switchgrass managed on annual or biannual harvest schedules.

The most promising areas for energy development based on land availability are located in the southern United States, and the Mid-west/Great Lakes States. However, the Pacific Northwest has provided a model for integrated research and collaboration with industry.

New hybrid poplar clones are being developed for the Pacific Northwest, the North Central, and Southeastern regions of the United States. Hybrid willow research is limited to the northeast and north central United States; and switchgrass variety development is occurring in the North Central, South Central, Southeast and Mid-Atlantic areas.

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The research and development strategy used by BFDP for developing energy crops is to create virtual "Crop Development Centers" within a region by facilitating collaboration among the best experts available (1). The strategies relies heavily on traditional genetic improvement programs. One core institution conducts the breeding, while others are recruited to conduct clone or variety trials and other supporting research. Linkages among researchers and institutions are facilitated by the BFDP to ensure that information from plant physiology, molecular genetics and biotechnology, pest and disease resistance, and silvicultural studies inform the breeding process.

2.1 Hybrid Poplar

Selection and breeding programs for hybrid poplars focus on improving productivity, and on disease and pest resistance. The BFDP supports breeding programs in the North Central and Southeast regions, while poplar breeding in the Pacific Northwest is now done by private industry. In the North Central region, the traditional breeding and selection work has recently produced twenty new cottonwood clones for regional testing and identified thirty-one clones as ready for full-scale testing in operational plantations. Yield improvements of the best clones range from 25 to 100% compared to controls.

Genetic transformation research has recently resulted in 73 Roundup Ready and 53 Bt transformed lines being made available to industry for field testing. The industry supported co-operative at Oregon State University is currently focusing on improving disease resistance and creating sterile clones.

Development and use of molecular maps is the focus of the industry supported Poplar Molecular Genetic Cooperative at Washington State University. In 1999 molecular markers linked to a Melampsora resistance gene (*Mmd1*) were used successfully in a marker assisted selection experiment for rust resistance.

Most hybrid polar crop management research is now being performed by companies under operational conditions. Areas of crop management still under improvement, particularly in the North Central and Southeast include fertilization, irrigation and weed control strategies. Several new commercial herbicides are greatly improving weed control options for poplar plantations.

The most serious disease for poplars in the United States is Septoria stem canker. Planting resistant or tolerant clones is the only control measure available to farm managers. New clones being tested will soon be added add to the relatively few clones now commercially available.

About 30–35 million hectares of operational plantings of hybrid poplars have been established to produce fiber and energy. An additional 15–20 million hectares of other short rotation crops (sweetgum, sycamore and eucalyptus) also have been established for fiber and energy products. BFDP collaborates with industry in sharing information on operational issues through the Short Rotation Operations Working Group.

2.2 Willow

Most willow research in the United States is being led by the State University of New York (SUNY) College of Environmental Sciences and Forestry (ESF) in collaboration with the U.S. Forest Service, Cornell University, Michigan State University, farmer-producers, and others. Activities include clonal selection, breeding, genetic improvement, management strategies (irrigation, spacing), understanding impact of production on soil microarthropods, willow cutting production scale-up, integrated pest management, operational issues dealing with planting, maintenance and harvesting, and a total economic analysis of costs of production. Outreach to communities and farmers is also an important part of the SUNY research program. The SUNY research effort is primarily funded as part of a Biomass Power for Rural Development Project initiated to demonstrate the use of residues and energy crops as a resource for co-firing in existing coal-fired power plants.

Willow clonal-site and genetic selection trials are ongoing in Quebec, New York, Pennsylvania, Michigan, Wisconsin, Delaware, Vermont, and North Carolina. Clones being used were derived from breeding programs in Europe and Eastern Canada. A new breeding effort has just been initiated to improve native willow material.

In 1999, over 1.5 million cuttings of willow were produced for operational plantings. This represents an increase of 85% over 1998 production levels. Associated research includes understanding long-term storage, handling and processing whips, and refinement of field operations.

By the end of the 2000 planting season, more than 200 hectares of willows will have been planted on farmer-owned land in western New York. Current plans include using a harvester imported from Europe for winter 2000-2001 harvests. Researchers and farmers are exploring multiple markets and uses for willow biomass, including phytoremediation, riparian buffers, waste stream management, living snow fences, and use of a carbon substrate for composting operations.

2.3 Switchgrass

A decision was made in 1991 to focus herbaceous crop research on switchgrass, a high yielding perennial grass species with potential for widespread use in the United States. Long-term yield studies have been conducted on 9 switchgrass cultivars at 18 sites. Over a 7-year period , post-establishment yields of the best cultivars ranged from 5 dt/ha year to 25 dt/ha/year, averaging about 16 dt/ha/year. Optimal harvest timing varied with location, 2 cuts per year gave highest yields in non-stressed systems, but 1 cut per year was better where drought stress was a problem.

Crop management research for switchgrass includes site-preparation, planting, establishment, use of chemicals for fertilizer, weed, or pest control, soil quality effects and harvest regime. About 50kg of N are usually applied during the first year after planting, followed by 80 to 100 kg/ha thereafter. Positive yield responses have bee found up to 224 kg/ha N. However, long term yield stability and economics may be improved by lower applications of N.

Switchgrass breeding "Centers" exist for the North Central, South Central, Southeastern and Mid-Atlantic regions. Initially, switchgrass breeding was based on recurrent restricted phenotypic election system. While yields were improved, inadequate seed set and low correlation between biomass yields of plants from year to year led to the adoption of an alternative approach. Genotypic recurrent selection is now being used.

Biotechnology tools under development for switchgrass include tissue culture techniques for clonal reproduction of parent plants, molecular fingerprinting, genetic mapping, and linkage of physiological traits to specific genotypes. To date, the genetic linkages among 18 existing switchgrass accessions in one germ plasm nursery and one commercial seed source have been identified. Genetic sequencing is being used to develop more complete molecular maps.

Large-scale plantings of switchgrass in Iowa and Alabama are associated with integrated bioenergy demonstrations in the Biomass Power for Rural Development initiative of the Biomass Power Program. Activities include all elements of crop production and infrastructure development needed to supply switchgrass feedstocks to user facilities.

2.4 Residues

Twenty seven million hectares of corn (maize) are grown annually in the United States. The stover (stalks, leaves, husks, and cobs) is a potential feedstock for chemicals and energy. Research is underway to reduce the cost of collecting, handling and transporting corn stover, and to determine the conditions under which stover can be removed without negatively impacting erosion control, soil carbon and soil nutrient levels.

3. BIORESOURCE SUSTAINABILITY

The BFDP conducts research and analysis to ensure that bioenergy technologies can provide environmental benefits without compromising economic viability. The work includes identifying sustainable crop production techniques and monitoring environmental effects of management strategies under operational conditions. Soil erosion, ground and surface water pollution, site productivity, biodiversity, and wildlife habitat are being monitored and documented. Stakeholder surveys suggest that the public will support production of energy from crops and residues only when the entire production cycle is shown to be environmentally sustainable and beneficial.

Biodiversity is a topic of particular interest. In Iowa, switchgrass plantings were found to extend habitat for bird species previously limited to wetlands by lack of available grasslands. The timing of switchgrass harvests will be critical to breeding success, and biodiversity benefits, in switchgrass stands. Mature hybrid poplar plantings in the Pacific Northwest provide habitat for bird species, particularly during the breeding season and to a lesser extent during fall migration. In a wintertime study , use of hybrid poplars by deer and medium sized mammals was most similar to use of open lands habitats.

Experimental scale studies in the southeast United States have addressed the environmental effects of converting agricultural lands to bioenergy crop production. Erosion, runoff, surface water quality, and subsurface movement of water and nutrients were compared for woody crops, switchgrass and agricultural crops at three locations in the Tennessee Valley. Results show that perennial energy crops and no-till annual crops can improve the physical quality of cropland formerly tilled annually. Cover crops between rows of trees improves erosion control and soil carbon gain

Studies at four sites in the southeastern United States show there is significantly more coarse root C under switchgrass and forest than under tall fescue, corn, or native pastures. Inventories of SOC under switchgrass do not different from other plant covers. Soil carbon research in the North Central United States has been complicated by significant variability in the data.

Research on the sustainability of removing corn stover from agricultural fields was initiated collaboratively with the U.S. Department of Agriculture in 1999. Data on nutrient, erosion, and carbon effects of corn stover removal is being developed at 5 locations in the upper Midwest.

4. BIOMASS SUPPLY ECONOMICS

Research data and expert opinion has been used to develop tools for estimating energy crop production costs. BIOCOST is a spreadsheet model that can be used to estimate crop production costs for hybrid poplars, switchgrass and willows (2) Default assumptions vary as a function of region but many of the assumptions can be modified by the user. The output from BIOCOST has been used to estimate production costs for hybrid poplars and willows in agricultural and forestry demand models.

A recent study evaluated the economic feasibility and ramifications of bioenergy crop production in the United States. An agricultural sector model (POLYSYS)was been modified to include switchgrass, hybrid poplar, and willow (3). Two scenarios were chosen to represent potential production policies. Scenario 1 assumed prices of 2.03 $US/GJ (or $US/dry tonne of $33, 34.9, and 36.2 respectively) for switchgrass, willow, and hybrid poplar at the farmgate. It also assumed use of wildlife management practices that resulted in reduction in harvestable yields for switchgrass. Scenario 2 assumed 2.70 $US/GJ (or $US dry tonne of $44, $46.5, or $43.8 respectively) for switchgrass, willow, and hybrid poplar. Normal production practices were assumed for all crops. In both cases, it was assumed that land in the Conservation Reserve Program (CRP) could be used and that those landowners would continue to receive 75% of the CRP rental rate originally negotiated with the government.

The resulting analysis indicated that under scenario 2 (farmgate prices of about $44/dt for switchgrass) 17 million hectares of cropland in the United States could produce energy crops at a profit greater than existing agricultural uses. At the lower farmgate price (about $33/dt for switchgrass) in scenario 1, only about 7 million hectares would be more profitable for energy crop production. Under both scenarios the largest portion of the landbase producing energy crops was existing cropland, but substantial amounts of CRP land were also used. At the higher price range the potential energy crop production level was 171 million dry tonnes, equivalent to 3.07 EJ of primary energy. This quantity could displace an estimated 253 million barrels of oil or supply an estimated 7.3 percent of the U.S. electricity needs. This level of energy crop production would also increase U.S. farm income by $US 6 billion.

Another analysis examined the potential availability of existing biomass resources in five categories as a function of price The graph below shows that at delivered prices of $55/dt or less (equivalent to $44/dt farmgate price) slightly over 450 million dry tonnes of cellulosic feedstocks could be supplied from urban wastes, mill, forest, and agricultural residues, and energy crops. Corn and wheat were the largest sources of residue, amounting to about 136 million dry tonnes.

7. CONCLUDING COMMENTS

Sufficient bioresources are available to supply at least 9 exajoules of bioenergy. This includes the 450 million dry tonnes of energy crops and residues estimated above, plus black liquor, a residual of pulp production which currently contributes over 1 exajoule to the primary biomass supplies in the United States.

Because the prices of energy crops and most residues are higher than energy facilities are now willing or able to pay for biomass, most bioenergy that will be produced in the near term will continue to be derived from lower cost urban and mill wastes, and black liquor. More research is needed on crop development and on supply logistics for all bioresources in order to reduce the cost of delivered feedstocks. The use of land for co-production of food, feed, fiber, chemicals, and energy may provide the profits needed by landowners to the amount of economically competitive bioresource supplies in the U.S. Understanding and quantifying the value of the environmental and economic benefits derived from woody crops and perennial grasses, and factoring those values into energy and environmental policy,is also likely to be necerssary to increase the supply of these crops for bioenergy.

More information about the research sponsored by BFDP including detailed project descriptions, papers, presentations pictures, and links to other relevant sites can be found at website:http://bioenergy.ornl.gov

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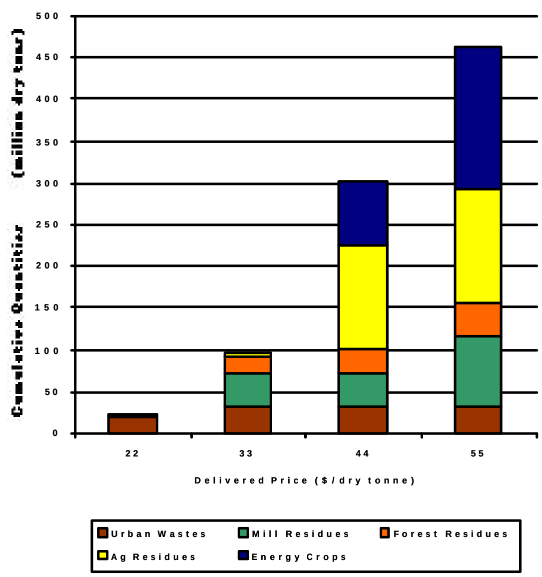

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