CONF-9508104--9

Energy Division/Environmental Sciences Division

ENERGY, ECONOMIC AND ENVIRONMENTAL IMPLICATIONS OF PRODUCTION OF GRASSES AS BIOMASS FEEDSTOCKS

Mark Downing
Sandy McLaughlin
Marie Walsh

August 1995

Prepared for the

Second Biomass Conference of the Americas
Portland, Oregon
August 21-24, 1995

Prepared by the
Oak Ridge National Laboratory
Oak Ridge, TN 37831-6205
managed by
LOCKHEED MARTIN ENERGY RESEARCH CORP.
for the
U.S. DEPARTMENT OF ENERGY
under contract number DE-AC05-96OR22464

ENERGY, ECONOMIC, AND ENVIRONMENTAL IMPLICATIONS OF PRODUCTION OF GRASSES AS BIOMASS FEEDSTOCKS

Mark Downing, Ph.D., Economist; Sandy McLaughlin, Ph.D., Forest Physiologist; and
Marie Walsh, Ph.D., Agricultural Economist
Biofuels Feedstock Development Program
Oak Ridge National Laboratory
Oak Ridge, TN 37831-6352 U.S.A.

Perennial prairie grasses offer many advantages to the developing biofuels industry. High yielding varieties of native prairie grasses such as switchgrass, which combine lower levels of nutrient demand, diverse geographical growing range, high net energy yields and high soil and water conservation potential indicate that these grasses could and should supplement annual row crops such as corn in developing alternative fuels markets. Favorable net energy returns, increased soil erosion prevention, and a geographically diverse land base that can incorporate energy grasses into conventional farm practices will provide direct benefits to local and regional farm economies and lead to accelerated commercialization of conversion technologies. Displacement of row crops with perennial grasses will have major agricultural, economic, sociologic and cross-market implications. Thus, perennial grass production for biofuels offers significant economic advantages to a national energy strategy which considers both agricultural and environmental issues.

Downing, Mark, Sandy McLaughlin and Marie Walsh. 1995. Energy, Economic, and Environmental Implications of Production of Grasses as Biomass Feedstocks. In: Proceedings of Second Biomass Conference of the Americas, Portland, OR. NREL/CP-200-8098, pp. 21-29.

Introduction

This paper will have four general parts. These include 1) U.S. energy markets and the niche which biofuels may fill, 2) the contribution to agriculture and scope of current agricultural production, 3) the role of technology in reducing barriers to market feasibility and 4) the significance of environmental issues. Crucial to understanding each of these four parts is in evaluating relationships among them and integration of these in any discussion of the potential for lignocellulosic inputs to the production of ethanol or other fuels produced by lignocellulosics. This is the reason for complexity and potential misunderstanding of any eventual benefits which may be derived from production of liquid fuels from renewable biomass sources. First, an understanding of the United States energy situation and opportunity for production of ethanol from lignocellulosic crops will be outlined. Second, agriculture, and more specifically, corn grain to ethanol in the U.S. is heavily subsidized and there are many incentives to produce traditional and conventional agricultural crops as a result. Economically, production and market incentives are strong. The technological development and advanced engineering is very capable of producing vast quantities of ethanol at a low price in a fixed market. Last, specific and significant environmental issues have recently have come to the forefront of the energy crop production debate. Environmental concerns have been voiced with respect to current agricultural production, but not with the intense scrutiny as potential alternative energy crops are.

After screening numerous annual and perennial species (Wright et al., 1994), the reduced cultivation, generally lower nutrient demand, and positive environmental attributes of the native American prairie grass, switchgrass, has led to its selection as a model herbaceous energy crop by the Department of Energy's (DOE) Biofuels Feedstock Development Program (BFDP) (McLaughlin, 1992). Research completed on this species to date, suggests that it could provide significant future ecological and economic advantages as well over annual crops such as corn. The energy, agricultural and agronomic, economic and environmental rationale for considering switchgrass as an alternative to corn is now presented.

Energy Situation in the United States

Transportation fuels in this country have been dominated by oil for nearly 100 years. Oil fossil fuels are neither endless in supply nor environmentally benign. Energy price shocks have proven costly as measured by the extent of their dislocative effects. While the time frame is uncertain, alternative fuels will need to be developed to replace current transportation fuels. A longer term perspective is important in developing bioenergy systems. Most current development in this area has been catalyzed by environmental mandates from the United States Environmental Protection Agency (USEPA). Development has also been attributed to economic factors in oil markets as a result of supply and demand shocks.

Fuel cell technology and methanol for internal combustion engines are two potential alternatives to gasoline. Fuel cells which generate electricity from fuels such as hydrogen and methanol are still being developed. Energy costs from fuel cells is currently seen as being greater than gasoline per unit of energy. If these fuels cells are operated from methanol, methanol is considered to further the greenhouse effect. If operated on hydrogen, remote generation of hydrogen would be necessary. Methanol to operate internal combustion engines is less expensive than gasoline, but must be produced from natural gas. This is seen to contribute nothing to reducing the greenhouse effect (Foody, 1988).

Ethanol is another alternative to fossil fuels for powering internal combustion engines and is the focus of this paper. Ethanol can be used as a blended fuel at 10 percent with 90 percent gasoline, or as a neat fuel (100 percent ethanol). It is currently used to enhance octane levels in gasoline, and acts as a co-solvent for other fuel additives. Its ability to substitute for other additives with harmful emissions may eventually add economic value above and beyond simply being an additive to gasoline.

The increased use of renewable fuels for energy offers the United States a strategy for significantly reducing national dependency on imported oil (Lynd et al., 1991; Robertson and Shapouri, 1993). There are several renewable feedstocks that can be used to produce ethanol, while providing diverse benefits to the national agricultural economy. Sugar, grain, and lignocellulosic biomass such as wood, agricultural residues, herbaceous crops such as sorghum, and switchgrass, and municipal wastes and paper are the most prevalent.

Current production of ethanol stands at 1426.5 million gallons in the United States. 1235 million gallons is produced from corn, the remaining from other sources (Gists-brocades, 1995). Projections for future supply and economic gain are derived based largely on the use of corn as the feedstock (Petrulis et al., 1992).

Net Energy Projections

The capacity of energy crops to offset imported energy will depend on the net energy return achieved in the series of energy consuming processes by which crops are grown, harvested and converted to energy. Extensive studies to date support the conversion efficiency of nearly 5:1 (units of energy out per unit in). Switchgrass requires less energy to produce than does corn. Corn produced per acre of land contains 50 million BTUs and requires 7.6 million BTUs to produce for an energy out-energy in ratio of 6.67.

Inclusion of corn stover improves the energy efficiency ratio to 8.8. An acre of switchgrass will produce 20.6 times the energy required to produce it if it is transported directly to the ethanol plant. The higher ratios for switchgrass result largely from the perennial nature of switchgrass (remaining in production for 10 years or more before replanting) and from lower chemical and fertilizer requirements. Chemical and fertilizer application for production were obtained from USDA (1991) and from The Fertilizer Institute (1988; 1992), DeLuchi (1991), and Pimental (1980). Transportation energetics were derived from Fluck (1992). Identical equipment complement assumptions were made for corn and switchgrass for preparation and planting; harvesting and handling equipment obviously varied (Fluck, 1985; and Bowers (1992)).

While net energy returns will vary somewhat regionally the energy advantage of grasses has been found to be consistently and significantly higher than for corn in all regions considered. The overall implication of the major portion of the differences among geographic production regions appears to stem from a net energy savings per unit of land used for perennial grasses as compared to corn.

Agricultural Benefit and Agronomic Potential

Perennial grasses were an ecological cornerstone of the early American prairie because of their forage quality and soil stabilizing attributes (Weaver, 1968). To date switchgrass has been bred primarily to enhance its nutritional value as a forage crop for livestock (Vogel, 1989). It has been managed primarily as a hay crop and early yields (4-17 metric tons per hectare (MTH)) have averaged approximately 60% above nation-wide yields for the 60 million acres of hay harvested annually in the United States (USDA, 1991). Recent research with several switchgrass varieties within the Department of Energy herbaceous crop research program (McLaughlin, 1992) is focusing more on total biomass production rather than foliage composition. This research and the evaluation of better adapted varieties has resulted in yields on research plots in Alabama as high as 35 MTH (Sladden et al., 1991) in a single year and 24 MTH over 5 years. During the latest test cycle yields have averaged approximately approximately 11 MTH across 17 locations in the Midwest and Southeastern United States for still aggrading 2 year old stands. These yields are being produced without irrigation, without the annual cultivation and planting cycle of annual crops, and with nitrogen and phosphorous fertilizer requirements that are typically one-fourth to one-half those for corn production. New breeding activities that are underway in the DOE sponsored BFDP are emphasizing increased total biomass production, and leaf nutrient contents. Some components such as nitrogen and potassium, may reduce biomass conversion efficiency. We estimate that 11-22 $MTHy^{-1}$ could be achieved with current varieties and production techniques in better switchgrass growing regions.

Economics

The Biofuels Feedstock Development Program staff and economists at Oak Ridge National Laboratory, and others, have extensively studied and researched the economics of switchgrass production and potential in the United States. These crop production budgets are being empirically verified now as the USDOE begins to fund large scale plantings of switchgrass for energy. Expansion of ethanol production from a current 0.8 billion gallon level to a level that will significantly offset dependency on foreign oil imports is anticipated to result in increased agricultural productivity, the creation of additional income for farmers, and thus implications for production of several types of crops. Based on the assumption that increased production will be achieved through increased utilization of corn, the United States Department of Agriculture's Economic Research Service (ERS) estimated agricultural impacts for two scenarios: an increase to 2 billion gallons by 1995, and 2) an increase to 5 billion gallons by 2000 (House et al., 1993). In the first scenario corn acreage is increased by 2.6 million acres and net farm income is increased by $153 million; in the second, acreage is increased by 9.3 million and net farm income increased by $1.6 billion. Significant effects on other crops and activities are not achieved until the second scenario, which is projected to result in a loss of $550. million in livestock production, because of increased feed costs associated with competition for corn as a biofuel.

Examination of the demographics of production, gain, and loss reveal some important regional discrepancies when additional bioenergy needs are met solely with corn. The net economic gain will be realized primarily in the current Corn Belt, Lake and Plain States that are already in primary corn producers. Cattle production losses will be spread more evenly across all cattle producing states. Thus, in spite of a national agricultural gain, the southeastern and mid-Atlantic states will experience a net economic loss which will be augmented by a loss of approximately 700,000 acres of soybean and cotton acreage associated with grain production shifts under increased corn production.

By contrast, a shift to reliance on perennial grass production could be effected using a much broader spectrum of land quality types, thereby impacting other crops minimally and spreading the benefits more evenly across the country. The southern states, which currently have a depressed agricultural economy, have provided the highest yields of warm season perennial grasses thus far, and would be among the most suitable target areas for biofuels industries.

Economic Factors Affecting Commercial Feasibility

Foody (1988) suggested that the technology for producing ethanol from biomass was improving rapidly and that laboratory reports were approaching the ultimate levels of techno-economic feasibility. Neat ethanol could compete in the current marketplace with gasoline at a price of $20. to $30. per barrel of oil. A successful demonstration of cost effective ethanol production would dramatically change the debate over major environmental problems that are energy related. Fuel ethanol's primary advantage is environmental as it is much cleaner burning than gasoline. When derived from lignocellulosic biomass, it is the only liquid transportation fuel that does not contribute to the greenhouse effect (Foody, 1988).

There are many additional factors that will affect the commercial feasibility. The ability to successfully develop enzymatic hydrolysis technology will be crucial. The process for making ethanol from lignocellulosic biomass involves seven major steps. Although complete treatment of each of these steps is beyond the scope of this paper, (see Foody 1988) they are biomass production, pretreatment, enzyme production, enzymatic hydrolysis, fermentation, distillation and by-product processing. Since each of these processes are interdependent, improving one may decrease the ability to make improvements in another. Finally, the ability to market by-products and co-products is crucial to the economic viability of any commercial system (ICAST, 1994).

Conservation Reserve Program

The Conservation Reserve Program (CRP) was initiated by the United States Department of Agriculture's (USDA) Soil Conservation Service (SCS) in 1985 largely to stabilize and improve soils degraded by over cropping. Over 36 million acres of land were idled by this law, primarily in the Great Plains and Southeast. Much of this land was replanted to perennial grasses, that had formed the principal species of the original American prairie. Predominant species were big bluestem, Indian grass, wheatgrass, and a particularly hardy and widely adapted and desirable species with potential energy use, switchgrass (*Panicum virgatum*).

The CRP program is at a critical point after 10 years of contracting with agricultural producers. Renewal or elimination options are currently being considered in the 1995 Farm Bill. Critics see the CRP as an unnecessary expense with questionable benefits to taxpayers. Recent consideration of both the resource conservation benefits of CRP and economic subsidy costs of returning these lands to annual row cropping suggests that CRP represents a gain to taxpayers (Kruse, 1994). Recent studies suggest that failure to renew the CRP will result in a rapid return of much of this land to annual row crops, notably wheat with significant downward pressure on existing wheat prices. An alternative to returning CRP to the same practices that necessitated its implementation initially, is to consider these lands for energy crops that can both preserve and enhance land quality and provide an economic return to the landowners. This possibility is strengthened by realizing that native perennial grasses that were planted under the CRP, are also excellent choices for production of transportation fuels.

Environmental Considerations

Soil conservation and augmentation is an important benefit from growing perennial grasses. The CRP has considered soil stabilizing properties and perennial grasses provide excellent protective cover and nutritive value to wildlife. Perennial grasses most obvious advantage over row crops such as corn is very significant reduction in soil erosion. Soil loss from erodable crop land can be staggering and results in loss of valuable nutrients from that land. One significant consequence is sedimentation and chemical input to and of adjoining areas and wetlands.

Contrast in erosion rates between continuous cultivation as row crops such as corn and perennial grasses such as switchgrass at many locations indicate that annual soil loss is accelerated typically 100-2500 times by continuous annual crop production (Shiflet and Darby, 1985). During heavy rains erosion differences can be even more marked.

Losses in soil organic matter are also increased by annual cultivation due to increase soil organic matter turnover as well as increased transport of topsoil (Buckman and Brady, 1960). The current rate of loss of soil organic matter (SOM) through annual row cropping practices in the United States has been estimated to be 2.7 million metric tons per year (CAST, 1992). This loss is important not only because it represents 7.5% of the total carbon released to the atmosphere by combustion of fossil fuels, but because SOM is critical to productive soils. Soil moisture holding capacity, soil density and aeration, and soil nutrient availability and conservation are among the essential properties controlled by SOM (Anderson and Coleman, 1985).

Recent studies of the changes in soil organic matter during 5 years of perennial grass production on CRP lands indicate that perennial grasses added 1.1 tons of carbon / ha^{-1} /

yr^{-1} to the upper 100 cm of CRP soils (Gebhardt, 1994). These additions replaced 23% of the soil carbon lost during decades of prior tillage. The large standing pools of roots, which can equal or exceed annual above ground production (Anderson and Coleman, 1985), and the rapid turnover of these pools, are the source of this carbon. Preliminary data from soils where switchgrass is being examined for energy production (Bransby et al., 1994) indicate that below ground root mass is very high totaling almost 8 MTH in just the top 75 cm. With Alamo switchgrass, over 1 MTH was found just in the interval 60-75 cm.

Summary

Perennial grass production for biofuels offers significant advantages to a national energy strategy which considers both environmental and economic issues. The benefits of using a native prairie species such as switchgrass to meet increasing an energy demand include improved soil quality, reduced soil erosion and associated pollution of aquatic systems, reduced emissions of greenhouse gases, increased efficiency of land and energy use, and a more equitable distribution of economic benefit to farmer-producers. To achieve these benefits in a timely manner will require we look beyond the relatively short term supplies of supply of municipal waste and crop and other residues to industrial feedstocks for future needs; crops grown specifically for a dedicated energy end-use.

Our planning should include accelerated commercialization of both ethanol conversion and grass fired combustion systems. It should also study the options for maintaining landowner participation in a conservation reserve program for which conservation objectives could be maintained by reduced subsidies and for involvement of landowners in energy crop production. The benefits to the national economy and national environment of such strategies appear too obvious to ignore.

References

Anderson, D.W. and D.C. Coleman. 1985. "The Dynamics of Organic Matter in Grassland Soils." *Journal of Soil and Water Conservation*. 40: 211-216.

Bowers, Wendell. 1992. "Agricultural Field Equipment," in *Energy in World Agriculture (6): Energy in Farm Production*, Richard C. Fluck (editor), Elsevier Amsterdam, pp. 117-129.

Bransby, D.I., R.H. Walker, D.W. Reeves, G.L. Mullins, and M.S. Miller. 1994. "Development of Optimal Establishment and Cultural Practices for Switchgrass as an Energy Crop." 1993 Annual Report to Oak Ridge National Laboratory, U.S. Department of Energy, Biofuels Feedstock Development Program.

Buckman, H.O. and N.C. Brady. 1960. *The Nature and Properties of Soils*. McMillan Co., New York. 567.

CAST. 1992. "Preparing U.S. Agriculture for Global Climate Change." Council for Agriculture, Science and Technology. Report 119. 93 p.

DeLuchi, M.A. 1991. "Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricity," Argonne National Laboratory.

The Fertilizer Institute. 1988. Energy Use Survey.

The Fertilizer Institute. 1992. Production Cost Survey.

Fluck, Richard C. 1985. "Energy Sequestered in Repairs and Maintenance of Agricultural Machinery," *Transactions of the American Society of Agricultural Engineers, 28:738-744.*

Fluck, Richard C. 1992. "Energy Conservation in Agricultural Transportation," *in Energy in World Agriculture (6): Energy in Farm Production*, Richard C. Fluck (ed.), Elsevier Amsterdam, pp. 171-176.

Foody, Brian. 1988. "Ethanol from Biomass: The Factors Affecting It's Commercial Feasibility." Iogen Corporation, Ottawa, Ontario, Canada.unpublished paper presented to Energy, Mines, Resources - Canada.

Gebhart, D.L. H.B. Johnson, H.S. Mayeux and H.W. Polley. "CRP Increases Soil Organic Carbon. *Journal of Soil and Water Conservation*, in press.

Gist-brocades. 1995. United States Ethanol Capacity. Gist-brocades BSD B.V. Charlotte, NC 28224-1068

Haas, H.J., C.E. Evans and E.F. Miles. 1957. "Nitrogen and Carbon Changes in Great Plains Soils as Influenced by Cropping and Soil Treatments." Technical Bulletin 1164. United States Department of Agriculture, U.S. Government Printing Office, Washington, D.C.

Hitchcock, S.S. 1951. "Manual of Grasses of the United States." United States Department of Agriculture, Misc. Publ. 200, 2nd edition.

ICAST. "Market Focus™, Ethanol and Co-Product Market Assessment," Saskatoon, SK March 23-26, 1994.

Jones, C.A. 1985. *C_4 Cereals and Grasses: Growth, Development and Stress Response*. John Wiley and Sons, New York.

Lynd, L.L., J.H. Cushman, R.J. Nichols, and C.F. Wyman. 1991. "Fuel Ethanol from Cellulosic Biomass." *Science, 231:1318-1323.*

McLaughlin, S.B. 1992. "New Switchgrass Biofuels Research Program for the Southeast." p.111-115. in *Proceedings of Annual Automobile Technology Development Contractor's Coordination Meeting*, Dearborn, MI, Nov. 2-5, 1992.

Miles, T.R., T.R. Miles, Jr., L.L. Baxter, B.M. Jenkins, and L.L.Oden. 1993. "Alkali Slagging Problems with Biomass Fuels." pp 406-421 *in Proceedings of the First Biomass Conference of the Americas*, Burlington, VT, Aug. 30 - Sept. 1993.

Moss, D.N., E.G. Krenzer, and W.A. Brun. 1969. "Carbon Dioxide Compensation Points in Related Plant Species." *Science 164:187-188.*

Pimentel, D. 1985. "Energy Inputs for the Production, Formulation, Packaging, and Transport of Various Pesticides," in *Handbook of Energy Utilization in Agriculture*, D. Pimentel (ed.), CRC Press, Boca Raton, FL.

Risser, P.G., E.C. Birney, H.D. Blocker, S.W. May, W.J. Parton, and J.A. Wiens. 1981. *The True Prairie Ecosystem. US/IBP Synthesis Series 16*. Hutchinson Ross Pub. 557p.

Robertson, T. and H. Shapouri. 1993. Biomass: An Overview in the United States of America. p1-17 in *Proceedings of First Biomass Conference of the Americas*, Burlington, VT, Aug. 30-Sept.2, 1993.

Sampson, R., P. Girouard, J. Omielan and J. Henning. 1993. "Integrated Production of Warm Season Grasses and Agro-forestry for Biomass." pp235-248 in *Proceedings of First Biomass Conference of the Americas*, Burlington, VT, Aug. 30 - Sept. 2, 1993.

References (continued)

Shifflet, T.N. and G.M. Darby. 1985. "Forages and Soil Conservation." pp21-32 in *Forages: The Science of Grassland Agriculture*, M.E. Heath, R.F. Barnes and D.S. Metcalfe eds., Iowa State University Press.

Sladden, S.E., D.I. Bransby and G.E. Aiken, 1991. "Biomass Yields, Composition and Production Cost for Eight Switchgrass Varieties in Alabama." *Biomass and Bioenergy 1(2):119-122.*

Stubbendieck, J. , S.L. Hatch, and C.H. Butterfield. 1981. *North American Range Plants.* University of Nebraska Press, Lincoln, NE 493p.

Swezey, Blair G., Kevin L. Porter, and J. Sherman Feher. 1994. The Potential Impact of Externalities Considerations on the Market for Biomass Power Technologies. NREL/TP-462-5789. National Renewable Energy Laboratory, Golden, CO.

U.S. Department of Agriculture. 1991. Economic Research Service, "Agricultural Chemical Usage," Washington, DC.

U.S. Department of Agriculture. 1991. Crop Production. 1990 Summary. U.S. Department of Agriculture National Agricultural Statistical Service, Washington, D.C.

Vogel, K.P., C.I. Dewald, H.J. Gorz, and F.A. Haskins. 1985. "Development of Switchgrass, Indiangrass and Eastern Gamagrass - Current Status and Future." pp51-62. in *Range Improvement in Western North America.* Proceedings: meeting of Society of Range Management, Salt Lake City, UT, Feb. 14, 1985.

Vogel, K.P., H.J. Gorz, and F.A. Haskins. 1989. "Breeding Grasses for the Future." Crop Science Society of America. Contributions from Breeding Forage and Turf Grasses, CSSA Special Pub. No. 15.

Weaver, J.E. 1968. *Prairie Plants and Their Environment: A Fifty Year Study of the Midwest.* University of Nebraska Press, Lincoln, NE. 276p.

Wiltsee, G.A., C.R. McGowin and E.E. Hughes. 1993. "Biomass Combustion Technologies for Power Generation." pp347-367. in *Proceedings of First Biomass Conference of the Americas*, Burlington, VT, Aug. 30- Sept. 2, 1993.

Wright, L.L. 1994. "Production Technology Status of Woody and Herbaceous Crops." *Biomass and Bioenergy*, vol.6(3):191-209.