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Energy production from forages (or American agriculture-back to the future)

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COMMENTARY

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At the turn of the century, with the exception of trains and water transportation, the transportation and agriculture industries of the U.S. were powered largely by herbaceous biomass. The herbaceous biomass was converted to usable energy by draft animals, primarily horses and mules. After 1900, automobiles, trucks, and tractors began to be used in transportation and agriculture. However, in 1920 there were still 25 million horses and mules on farms and ranches and 2 million draft animals in the cities of the United States (Ensminger 1955; Census of Agriculture 1920). The energy requirements of these animals were considerable. In the midwest, the feed requirements for a work horse during the six month crop growing season were 5,200 lbs of roughage (hay or herbaceous biomass), 3,200 lbs of concentrate, usually oats, and pasture (Williams and Speelman 1934). Horses were an important source of power during and immediately after World War II. By 1954, U.S. agriculture and industry was largely powered by gasoline, diesel, or electrical motors and there were only 5 million horses and mules in the U.S (Census of Agriculture 1954). The decrease in the numbers of draft animals released approximately 80 million acres of land for other purposes (Census of Agriculture 1954).

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The haylands and pasturelands that were released from herbaceous biomass production due to the decrease in draft animals were used for other agricultural purposes. In many cases, this was conversion to grain crop production. This massive conversion of land plus the increases that have been obtained in grain crop production led to huge grain crop surpluses which depressed grain prices and severely damaged farm incomes. As a result of the surpluses, the U.S. government has had a series of programs for taking land out of production. These included the Soil Bank program, Conservation Reserve Contracts, Feed Grain, Wheat, and Cotton Diversion Programs (Barlow 1979), and the recent Conservation Reserve Program. During the period 1957 to 1975 there was a minimum of 20 million acres of land a year held out of production by these programs (Barlow 1979). Due to crop failures in the Soviet Union in the early 1970s, an increased demand for grain resulted in the elimination of many of these programs. By 1975, there were only 2.4 million acres in some type of diversion program. In the early 1980s, the demand for U.S. grains in world markets decreased and again large crop surpluses developed, commodity prices dropped, and farm incomes suffered which led to the Conservation Reserve Program.

The population of the United States has doubled since the U.S. converted from horse power to machine power. The increase in agriculture productivity per acre has met the food demands of the United States as well as providing food for export (Barlow 1979). Much of the land that was released from biomass energy production by the conversion from horse power to machine power is not needed at the present time to meet the food and fiber requirements of the United States as indicated by the current Conservation Reserve Program.

At the beginning of this century, the agricultural landscape of the United States was different than what exists today. Because of the need to have forage for horses and mules, each farm had pastures and hayland. In 1900, there were 185 million acres of cropland in the U.S. and 61 million acres of hay and pastureland (Census of Agriculture 1900). The pastureland was typically on the poorer parts of the farms including some of the fields with the greatest slopes. The hayland was farmed in rotation with other crops. Often, one fourth or more of a farm was in hayland or pasture. The conversion of this land to grain crop production increased the land area subject to soil erosion. As a result, one of the goals of all the crop diversion programs has been reduction in soil erosion.

Grasslands reduce soil erosion by intercepting precipitation, energy dispersion, increased infiltration and reduced runoff nearly eliminating sediment delivery (Table 1) (Wadleigh et al. 1974). The reduced erosion and other positive attributes of grasslands produce both on-site and

Table 1. Effects of cropping on soil erosion

Treatment	Annual soil loss (tons/acre)*		
	LaCrosse, WI	Guthrie, OK	Clarinda, IA
Continuous Corn*	12	33	37
Rotation Row Crop	53	3	18
Rotation Grain	30	7	10
Rotation Hay	0.7	2.5	5
Grassland	0.1	<0.1	<0.1

*Data extracted from Wadleigh et al. 1974.

off-site benefits. The benefits were incorporated into the proposed benefits of the Conservation Reserve Program.

The benefits of the Conservation Reserve Program include reduced soil erosion, protection of soil productivity, reduced sedimentation in downstream rivers, lakes, and reservoirs, improved water quality, and improved habitat for fish and wildlife. Direct economic benefits include decreasing crop surpluses and associated commodity payments and increasing farm income (Ribaudo et al., 1990). In an economic analysis, Barbarka and Langley (1992) using simulation of crop markets predicted that the CRP program will have reduced crop commodity payments during the term of the program by $9.7 billion dollars. The total CRP program at its completion is expected to have cost $18.2 billion dollars. The direct costs are expected to exceed direct benefits by $8.5 billion dollars (Barbarka and Langley 1992). Predicted indirect benefits of the program include improved water quality ($1.3 to $3.9 billion), improved value to hunters ($1.9 to $3.1 billion), onsite soil productivity benefits ($1.2 billion), and wind erosion benefits ($400 million) (Ribaudo 1989; Osborn and Konyar 1990). At best, the Conservation Reserve Program will probably be a break-even program. A recent estimate indicates the net program cost by 1999 will be between $2 and $6.6 billion (Zinn 1993).

The environmental benefits due to reduction in erosion achieved by converting marginal land to grasslands vary with region, land capability class, and soil type (Larsen et al., 1983). These benefits are all positive (Wadleigh et al., 1974; Weil et al., 1993). However, to date, converting marginal lands to grasslands through government land diversion or set-aside programs have not been cost effective or a long-term means of dealing with the land that was released from energy production by the shift from horse power to mechanical power.

The U.S. Department of Energy (DOE) is interested in developing renewable energy sources such as ethanol for use in the transportation industry. At the present time, ethanol is produced by fermenting the starch in grains using classical fermentation procedures. Ethanol could be made from other plant products if processes were developed to convert the plant material to ethanol. The most abundant plant materials in the world are plant cell walls. Forage crops such as switchgrass excel in the production of plant cell walls. Plant cell walls are comprised primarily of cellulose and hemicellulose. These macro molecules are comprised of simple sugars, glucose and xylose, that are held together by chemical bonds that are different than the bonds that hold glucose molecules together to form starch. The plant cell walls are not fermentable using classical fermentation procedures.

Table 2. Forage yields of the five highest yielding switchgrass strains at three midwestern locations in 1991 and 1992*

	Cut1ton/A	Cut 2 ton/A	Total ton/A	Gross return $/A†	Gal/A ethanol‡
Mead, NE	6.0	0.4	6.4	320	505
Ames, IA	5.4	1.1	6.5	325	513
West Lafayette, IN	6.1	0.9	7.0	350	553

*Data from Hopkins et al., 1995.
† Biomass priced at $50.00/ton.
‡ Assumes conversion rate of 79 gallon/ton of biomass (Turhollow et al. 1988).

Recently molecular genetics research has made significant advances in making ethanol production from biomass feasible (Zhang et al. 1995; Ingram et al. 1987). In the most recent development, Zhang et al. (1995) reported producing a recombinant bacteria that can anaerobically ferment both xylose and glucose sugars to ethanol at yields exceeding 86 percent of theoretical yield. Research also is being conducted on procedures to break cellulose and hemicellulose down into simple sugars. Research has reduced the cost of producing ethanol from biomass from $3.60 per gallon in 1982 to $1.35 in 1992 (Wyman 1992). With improvements in both conversion technology and biomass plant productivity, it is estimated that it may be feasible to produce ethanol at $0.60 per gallon by 2010 from herbaceous biomass (Wyman 1992). At a cost of $0.60/gal it would be equivalent to petroleum fuels at $25/barrel for crude oil (Wyman 1992).

In a series of evaluation trials with cooperating state universities and the U.S. Department of Agriculture, the Department of Energy has identified switchgrass, a native warm-season perennial prairie grass as the most promising species for development into a herbaceous biomass fuel crop. It has an array of desirable attributes that include broad adaptation, high yields, and stress tolerance and it is harvestable with conventional hay-making equipment. Its principal attribute is that it can produce high yields on marginal lands that are unsuitable for row crop production due to high erosion potential. The Department of Energy, USDA, and cooperating state experiment stations are currently conducting breeding and management research to improve switchgrass as a potential biomass crop.

As part of this research, currently available switchgrass cultivars and experimental strains were evaluated in trials in Nebraska, Iowa, and Indiana for their potential as biomass fuel crops (Hopkins et al., 1995). The research plots were seeded in 1991 and harvested in 1991 and 1992. They were fertilized with 100 lb N per acre. The only other cultural practices were the harvesting operations. The highest yielding strains produced 6 to 7 tons dry matter per acre (Table 2). Turhollow (1994) estimated that switchgrass would have to sell for $39 to $54/ton to be competitive with corn in the midwest. At a price of $50/ton, the gross return per acre would be over $320 per acre (Table 2). Assuming 75 percent conversion of the constituent cellulose and hemicellulose to ethanol, these yields would result in ethanol production of more than 500 gallons/acre (Table 2).

Average corn yields for the counties in which the switchgrass trials were located ranged from 76 to 162 bushel per acre (Table 3). In the Midwest, 1991 was a drier year than average while in 1992, the growing season was cooler than average. The average gross return per acre for corn for the three counties averaged $245 to $300 (Table 3). Assuming a conversion rate of 2.9 gallon of ethanol per bushel, the average ethanol yield from corn from these three Corn Belt counties would have been 330 to 413 gallons per acre (Table 3).

A family car that is driven 10,000 miles and gets 20 miles per gallon will use 500 gallons of fuel per year. Since ethanol has only about 65 percent of the energy content of gasoline, it would take about 770 gallons of ethanol or the production from 1.5 acres of switchgrass at existing productivity levels to meet the fuel demands for this car. It would take 1.8 acres of 150 bushel corn to supply the same quantity of ethanol. However, ethanol is now being commercially produced from corn but no plants for ethanol production from switchgrass are in production. If the conversion technology can be improved sufficiently to reduce the costs of producing ethanol from biomass, switchgrass would appear to have considerable promise as a biomass fuel crop because the feedstock costs would be lower than that of corn over a considerable price range (Table 4).

Herbaceous biomass fuel plants such as switchgrass would have to be grown east

Table 3. Non-irrigated corn yields and gross return for three counties in which switchgrass trials were conducted in the midwest (USA) in 1991 and 1992

Location	Yield bu/A*		Corn price† $/bu		Average gross return $/A	Ethanol yield‡ gal/A
	1991	1992	1991	1992		
Saunders County, NE (Mead)	103	133	2.34	2.05	257	342
Story County, IA (Ames)	123	162	2.30	1.95	300	413
Tippecanoe County, IN (W. Lafayette)	76	152	2.45	2.00	245	331

* National Agricultural Statistics Service databases, National Agricultural Statistics Service, U.S. Dept. of Agriculture.
† Agricultural Statistics 1993.
‡ Assumes conversion of 2.9 gallons of ethanol/bushel of corn (Turhollow et al., 1988).

Table 4. Feedstock costs for biomass fuels*

Switchgrass		Corn	
$/Ton	$/gal. ethanol	$/bushel	$/gal. ethanol
40	0.51	2.00	0.69
50	0.63	2.50	0.86
60	0.76	3.00	1.03
70	0.89	3.50	1.21

* Assumes 79 gallons of ethanol produced per ton from switchgrass biomass and 2.9 gallons of ethanol produced per bushel of corn (Dobbins et al. 1990; Turhollow et al. 1988).

of 100° W. Long. because of precipitation requirements for economic yields (Graham 1994). In this region, which is basically east of a North to South line 200 miles west of Omaha, NE, there are 20 to 40 million acres of land that could be converted to biomass crop production without significant displacement of crops (Graham 1994).

Use of marginal lands for biomass fuel production could convert a substantial portion of the land that was used for energy production at the turn of the century from grain or commodity crops back to energy production. The onsite and offsite benefits for this conversion would be the same as for the Conservation Reserve Program. If the biomass can be converted to liquid fuels as economically as predicted and adequate yields can be obtained, this conversion of land back to energy production could be achieved without the need for massive federal subsidies.

Grasslands are sustainable agricultural systems. Incorporating grasslands into agricultural systems improves the sustainability of the entire system. If fuel production from biomass becomes a national reality, the rural landscape of many areas of the United States will be changed. It will resemble the landscape of the United States at the turn of the century when substantial areas of rural America were in grasslands and haylands. Combined with the conservation tillage techniques that can now be used for grain crop production, major improvements in the sustainability of agroecosystems of the U.S. could be achieved. Our agricultural production systems would be more sustainable than they were at the turn of the century when clean tillage was practiced on many of the grain crops.

Biomass could be a new crop for farmers that will likely be a reliable source of income and will aid in buffering their income from price swings in grain prices. In addition, there will be other positive environmental and economic benefits for all citizens of the U.S. including cleaner water and air, reduced support for farm programs, and reductions in trade deficits due to energy importation. The shift from biomass power to machine power was not made as a result of a government program but was made by individual farmers. It is doubtful if the conversion of land back to energy production can be achieved without stable, long-term programs for biomass energy production.

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