FORAGE CROPS AS BIOENERGY FUELS: EVALUATING THE STATUS AND POTENTIAL

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ABSTRACT

The use of forage crops as a source of renewable energy for generation of electricity, transportation fuels, and chemical feedstocks is a concept with tremendous relevance to ecological and economic issues that we must face now and in the years ahead. Development of a significant capacity to utilize forages as biofuels could benefit our agricultural economy by providing a new source of income for farmers. In addition it could reduce degradation of agricultural soils, lower national dependence on foreign oil supplies, and reduce emissions of greenhouse gases and toxic pollutants to the atmosphere. Whether this potential will be realized or not will depend on the simultaneous development of high yielding biomass production systems and bioconversion technologies that efficiently convert biomass energy into forms usable by industry. The endpoint criterion for success is economic gain for both agricultural and industrial sectors at reduced environmental cost and reduced political risk. This paper reviews the issues that are being addressed to aid in development and evaluation of renewable energy from biomass. It specifically draws on analyses of the attributes of switchgrass, a native prairie grass being evaluated as a bioenergy species on a national scale by the Biofuels Feedstock Development Program at Oak Ridge National Laboratory. Feedstock attributes, management issues, current research efforts, and economics of production and industrial utilization are discussed as they relate to larger scale use of forages for biofuels.

KEYWORDS

bioenergy, rationale, forages, economics, soil conservation

INTRODUCTION

The concept of dependence on large acreages of forage grasses to produce significant amounts of energy for transportation is not a new one. Rather it has its roots in a 19th century America in which transportation and work was carried out by draft animals, primarily horses and mules (Vogel, 1996). In the United States, approximately 34 million hectares (ha) was dedicated to feeding the approximately 27 million draft animals that performed this work as of 1920. By 1954, replacement of " grass power" with fossil fuel power used to fuel automobiles, trucks, and farm machinery had displaced approximately 22 million draft animals and released 32 million ha of land (Vogel, 1996).

Today a new form of energy production is envisioned for some of this same acreage. The methods of energy collection are exactly the same, solar energy captured in photosynthesis, but the end uses envisioned are vastly different. The recovery of the chemical energy contained in biomass, including trees, grasses, and annual crops can be accomplished by a wide variety of processes. These include chemical conversion to ethanol and other transportation fuels; conversion to secondary chemical feedstocks that can be used in a variety of industrial processes; and direct combustion to produce heat and/or electricity. Fuels for these processes may include dedicated lignocellulosic crops, such as forage grasses and trees, annual crops such as corn, as well as municipal and agricultural wastes. Among the most promising of these are the forage grasses, which combine attractive ecological and environmental attributes with high compatability with existing farming systems. This paper will review several important issues that relate to the realization of biomass energy in general and forage grasses in particular as a significant addition the United States' energy supply system.

THE RATIONALE FOR RENEWABLE ENERGY

The rationale for developing supplies of renewable energy includes considerations of national security issues, regional and global environmental issues, and agricultural economics. From a national security perspective, reducing our national dependency on foreign oil supplies has the multiple benefits of reducing the economic risks of disrupted oil supply, reducing the military risks of armed intervention to protect fuel supplies to America, and decreasing the flow of US currency to overseas markets (Green and Leiby, 1993).

At present, imported oil accounts for approximately 44% of the foreign trade deficit in the USA and about 45% of the total annual US oil consumption of 34 quads (1 quad = 10^{15} Btu, Lynd et al., 1991). Approximately 97% of this oil is used in transportation. This oil has costs, which go well beyond the purchase price of around $20 per barrel. These costs include environmental costs of pollution during drilling, transport, and combustion; the societal costs of dramatic price fluctuations effected by supply crises; and the military costs of establishing and maintaining assurance of uninterrupted oil flow to the US (Greene and Leiby, 1993). Collectively these costs may sum four or more times the actual purchase price of oil.

From an environmental perspective the combustion of fossil fuels is accompanied by releases of greenhouse gases such as CO2, which contribute to global climatic change, and sulfur and nitrogen oxides which contribute significantly to regional atmospheric pollution. Biofuels, by contrast, produce significantly lower levels of inorganic pollutants, and little if any net increase in atmospheric CO2, since the carbon released is recaptured by the growth process. The issue of reduced carbon emissions through bioenergy production will be discussed later.

Oil, coal, and natural gas consumption represent approximately 42%, 23%, and 24% respectively of the 85 quads of energy used annually in the US. These are non-renewable resources which contribute significantly to global increases in atmospheric CO_2. Estimates of total recoverable reserves of petroleum and natural gas in the US at current usage rates were only 16 and 35 years respectively in 1989, while coal reserves were judged to be sufficient for more than 1000 years (Lynd et al., 1991).

While research on renewable fuels is being conducted at a time when relatively low cost fossil fuels are still available, the perspective for judging success should extend well beyound the present and include values more inclusive than the existing purchase price of the fuels. Biomass fuels represent an attractive alternative to fossil derived energy, particularly if the evaluation considers future energy usage rates and likely future energy prices.

On a world scale approximately 360 quads of energy are used each year, and this figure is expected to increase by 66%-230% in concert with World bank estimates of an approximate doubling of world population during the next 100 years (Sheffield, 1996 [1]). Thus, with the exception of coal, perhaps the environmentally least attractive

[1] Data from " Biomass energy- A vision for 2025". Presentation by John Sheffield at Bioenergy '96 Conference, September 16, 1996. Nashville, TN. Summary handout, Energy Technology Program. Oak Ridge National Laboratory, Oak Ridge,TN.

of the fossil fuels, increasing future energy demand will be levied against a dwindling supply of traditional energy reserves. Future energy costs will increase significantly as supplies diminish and with the likely imposition of pollution based taxes. This trend is already apparent in countries like Sweden where the carbon emissions tax on coal is $60-200 per ton (Swedish Institute, 1995).

Benefits to US agriculture are among the most significant arguments for a biofuels industry which will depend on on-farm production and sale of renewable feedstocks. Those benefits include both increased revenues to farmers as well as potential imrovements in soil conservation where perennial grasses replace annual row crops (McLaughlin et al., 1994). So what is the potential for biofuels and specifically for forage crops to contribute to future energy production and what are the factors that will influence this potential?

EVALUATING POTENTIAL MARKETS FOR BIOFUELS

Biofuels and Bioenergy Products - There are two basic categories of biofuels and three principal endpoint processes for recovering biofuel energy. Biofuel categories include (1) biological residues from agricultural, forestry, and municipal wastes and (2) dedicated energy crops. Major end use categories include chemical conversion to liquid fuels, combustion to produce heat or electrical energy, and gasification which produces syngas that can either be burned to produce heat or converted to secondary chemical products, including transportation fuels.

Wastes will likely play an important role in the early stages of development of biofuels markets, but most projections indicate that these more diffuse sources will be inadequate to supply significantly expanded future markets at acceptable prices. Contributions of agricultural, forestry, and municipal solid wastes were recently estimated at from 17-44% of the potential energy potential that could be provided by dedicated feedstocks (Lynd et al., 1991). Dedicated feedstocks, because they will be concentrated around utilization points will reduce transportation costs and improve stability of supply.

Among the dedicated feedstocks there are major differeces in production systems designed to provide wood and herbaceous crops. Short rotation forests are typically cut on 6-12 year cycles while herbaceous crops are harvested annually. The Oak Ridge National Laboratory, Biofuels Feedstock Development Program (BFDP) has examined many candidate biofuels species, but currently is focusing most of its field research on two species hybid poplar, *Populus* a fast growing tree, in which there is substantial interest by timber industries, and switchgrass (*Panicum virgatum*), a native prairie species (Wright, 1994). Switchgrass is a perennial forage grass in widespread use in the U.S. Conservation Reserve Program because of its soil conservation and wildlife cover potential (Gebhardt et al., 1994 and McLaughlin et al., 1995).

These energy crops are classified as lignocellulosic crops because it is primarily cell walls that are converted to recoverable energy as the stem, stalks, and foliage (in the case of forages) are utilized in energy production. This is in contrast to energy recovery from corn grain, where digestion and fermentation of starch to produce sugars and ethanol is a well established technology (Wyman, 1993). The rationale for developing lignocellulosic crops for energy is that less intensive production techniques and poorer quality land can be used for these crops, thereby not competing with food production on better quality land.

Much of the early emphasis on biofuels has been on production of ethanol as a transportation fuel (Lynd et al., 1991). DOE has sponsored a significant research effort to produce ethanol from lignocellulosic crops through the SSF (Simultaneous Saccharification and Fermentation) processs (Wyman, 1993), a combination of chemical and/or physical digestion followed by microbial fermentation. In the SSF process biofuels are broken down to organic residues that can be enzymatically converted to sugars and then fermented by microbes to produce ethanol. This is a relatively expensive technology because of the costs of acids and enzymes used in digestion. Ethanol yields are limited to 50-80% of possible levels, partly because lignin cannot be broken down by this process. On the other hand, recovered lignin has a high energy content and can be used as an energy input to the ethanol recovery process in SSF (Tyson et al., 1994). Pilot scale testing of this technology is underway with the first commercial plant targeted for the year 2000.

Another technology for producing both ethanol and a variety of other liquid fuels and chemical products is gasification. Gasification is a process that has been available for many years as a means of converting coal, natural gas, or solid wastes into synthesis gas, primarily hydrogen and carbon monoxide. Syngas can then be burned to produce heat or chemically synthesized into a wide variety of secondary products, including ethanol, diesel fuels, and chemical solvents used in industrial processes. Gasification has the benefit of converting essentially all of the carbon in biomass into synthetic gases.

While the conventional syngas technology, the Fischer-Tropsch system used high heat and temperature to synthesize secondary products, there are newer systems currently under development that use the biological capacity of microrganisms in reaction cells to produce synthetic products such as acetic acid, ethanol, and many other useful organic chemicals (Kaufman, 1996). The advantage of these biological reaction cells, which have been developed largely with research support from the U.S. Department of Energy, is that they operate at near ambient temperatures and pressures, resulting in greatly reduced costs, and with greater chemical specificity than the Fischer-Tropsch process.

The range of primary and secondary chemical products that can be produced from gasification is shown in Figure 1. It demonstrates the versatility that gasification offers in both accepting variable feedstocks and in producing chemical products useful for a broader industrial market. The broader development of gasification and the bioreactor concept will likely play an important role in the utilization of biomass feedstocks for a more diverse range of industrial endpoints.

The final category of biofuel use is in combustion to produce heat or electrical power. At present there are approximately 7000 megawatts (MW) of power produced from biomass in the USA (DOE, 1996). This is derived largely (90 %) from wood wastes at wood processing plants operated by the timber industry around the US. A much broader use of wood and other biomass energy from dedicated feedstocks is envisioned in the future. The US DOE in 1991 formed the National Biomass Power Program to help achieve a concerted national program to promote the development and use of biomass power. This program is strongly based on collaboration with the US Department of Agriculture (USDA) and private industry to form the government-industry partnerships necessary to achieve success. This effort will involve both direct combustion of biomass feedstocks co-fired in electric boilers with coal and other fuels, as well as gasification, an energetically more efficient process.

While wood wastes form the greatest fraction of current biomass-derived power production, there is great interest in using forage grasses for biopower as well. The DOE has recently embarked on two cooperative efforts to develop and utilize forage crops for power production. One involves the use of switchgrass in power generation (6 MW) with the Chariton Valley (Iowa) Resource Conservation and Development Agency. The second involves a joint effort with the Minnesota Valley Alfalfa Producers to produce electricity (from alfalfa stems) and animal feed from alfalfa leaves. These first commercial scale implementation efforts should provide valuable information on agricultural, sociological, and economic issues involved in a regional biomass power program.

EVALUATING THE LAND BASE AND POTENTIAL MARKET SIZE OF BIOFUELS

The current biofuels industry in the US is based almost entirely (98%) on conversion of corn to ethanol (Petrulis et al., 1993). At present 1.3 million hectares, approximately 6% of the United States' corn crop, is used in production of approximately 1 billion (B) gallons of ethanol each year. Estimates of future corn production of ethanol have been as high as 5 billion gallons per year with potential net benefits to agricultural income of over $ 1 billion to US farmers (House et al., 1993). However, recent analyses suggest that it is unlikely that corn can supply more than 2-2.5 B gallons of ethanol annually because of competing demands for corn. How much this figure will actually increase in the future depends largely on the success of agricultural, economic, and industrial research currently underway, including the development of markets for lignocellulosic crops.

Success of a biofuels industry will depend on the capacity of biofuel crops to provide an economic return comparable to conventional crops on the same land or to provide an acceptable return, or benefit, on poorer quality land not suited for traditional cash crops. The potential land base suitable for energy crop yields of 11.2 Mg ha^{-1} yr^{-1} (11.2 megagrams per ha = 5 tons per acre) has been estimated to be up to 131 million (M) ha with somewhat higher acreages being suitable for herbaceous energy crops such as switchgrass (131 M ha) compared to tree crops 91 M ha (Graham, 1994).

The potential land area that could be incorporated into biomass crop production by 2012 has been estimated at 60M ha, with an approximate ethanol energy production potential of 8.5 Quads (1 quad = 10^{15} btu). This would displace about 25% of current total annual US petroleum consumption (34 quads) and about 55% of imported petroleum (Lynd et al., 1991). If the additional 60 M ha of convertible cropland and 39 M ha of forest land that could be used for short rotation forestry were included, the total potential contributions of biomass fuels could provide up to 50% of total petrochemical use and displace all of imported oil.

How much land will actually be used for energy crop production will, of course, be dependent on many factors, but primarily on the net profits to both industry and agriculture. Lynd et al. (1991) estimated that approximately 75 M acres of idled land was available for biomass crops in the US in 1988. Increased land availability is envisioned to come largely as a result of improved agricultural productivity (Robertson and Shapouri, 1993). Ferrell et al. (1995) recently projected that as much as 12 million hectares of land may be dedicated to energy crop production by the year 2010. At projected yields of 12 Mg of biomass ha^{-1} y^{-1} and a purchase price of $35 Mg^{-1}, a gross income of approximately $ 5 billion could be generated annually for biomass growers at these levels.

In actuality, land available for biofuels will have to supply two sectors, transportation fuels and power generation. Projected production of biomass power has been estimated to increase to a level of 30, 000 MW, or more than 4 times current levels, by the year 2020 (US DOE,1996). To approximate the land area needed to provide this energy using a dedicated forage crop like switchgrass it is assumed that 50 % energy recovery is achieved from biomass produced at 12 Mg ha^{-1} and having an energy content of 18.4 Gigajoules Mg^{-1} as a dry fuel (McLaughlin, 1996). The calculated land area required to produce this amount of energy would be approximately 9.0 M ha. On a national scale this would supply approximately 4% of the total and 32 % of non-utility power generation, respectively (US DOE, 1996).

THE CASE FOR FORAGE CROPS

Among the dedicated feedstocks forage crops are particularly attractive as biofuels because they can readily be interfaced with existing farming operations and they combine both environmental and socio-economic benefits (Paine et al., 1996). Forages can be produced with conventional farm equipment and can be fed to cattle as an alternate endpoint to biofuels markets. Short rotation forestry requires much more expensive harvesting equipment making it more suitable for cooperative ventures between landowners and timber production companies. By contrast the individual landowner who harvests hay as a component of his farming operation, can easily become involved in producing forage crops as biofuels. Equally important from the landownwers' perspective is the flexibility of rapidly moving back to other crops as market conditions dictate.

The BFDP at Oak Ridge National Laboratory has examined a wide variety of herbaceous species, including both annual and perennial crops, for suitability as biofuels (Wright, 1994). Consideration of yield performance data, economic costs of production, and environmental attributes led to selection of a native forage grass, switchgrass, as the model species for an integrated research program (McLaughlin et al., 1992). The program was initiated in 1992 to evaluate and improve productivity of switchgrass in the Southeast and Southcentral US . Additional research on the economics of switchgrass production and the demographics of potential production form important components of the programmatic evaluation of the potential of switchgrass as a bioenergy crop.

Current Switchgrass Productivity Research - Switchgrass (*Panicum virgatum*) is a perennial warm season grass with a high water and nutrient use efficiency, a wide range, and high genetic diversity (Moser et al., 1995). It has been widely planted in the Conservation Reserve Program because of it provides good soil erosion control and excellent wildlife cover. In addition it is a native species that was a significant component of the midwestern tall grass prairie (Weaver, 1968), a regionally important ecosystem that has been significantly depleted by annual row crop agriculture (Samson and Knopf, 1994). Since it was also a good forage grass with a broad range of adaptability, switchgrass was an excellent candidate upon which to base a regional biofuels research program.

The present switchgrass production research program within the BFDP involves a total of 8 collaborating institutions involved in multidisciplinary research in the areas of management, physiology, breeding, and biotechnology as shown in Figure 2. The program is structured to meet the near term objectives of rapidly evaluating yield potential of existing cultivars under a wide range of field conditions, while at the same time developing the physiological and genetic tools to pursue the longer term objectives of crop improvement and protection (Sanderson et al., 1996). Technical progress to date has been excellent. Nine switchgrass cultivars have been evaluated across a network of 19 research plots. Annual yields of the best varieties have averaged about 16 MG ha^{-1} across all plots with yields in excess of 22 Mg ha^{-1} occurring at the best plots. The highest yielding varieties have been lowland varieties Alamo and Kanlow at Southern and Mid-Atlantic sites, while the upland variety Cave-in-rock, performs well most consistently in the central plains to the North.

The management issues with greatest impact on utilization of switchgrass as a biofuel are establishment, the timing and frequency of harvests, and nitrogen and fertilization strategies. A firm seedbed, proper planting depth, and good weed control during the first year are very important to good switchgrass establishment (Wolf and Fisk, 1995). The search for a safe herbicide to be used with switchgrass on a production scale has been an important objective of the BFDP research program. Researchers at the University of Nebraska have now identified Plateau as an excellent candidate and a collaborative testing and approval program with American Cyanamide is now under way. Plateau may now be used on grasses that will not be grazed and is anticipated to be cleared for forage use within 3 years (Bob Masters, Personal Communication).

After the establishment year, when it is typically not harvested, switchgrass may be cut once to multiple times during a single season depending on the management objectives. Both the total yield and the quality of biomass for use as a forage for cattle or as a biofuel may be significantly influenced by cutting frequency. With frequent cutting a higher leaf to stem ratio will be achieved, and the resultant feedstock will have a higher nutritional value for cattle. For use as a biofuel, later cutting generally improves fuel quality since a higher cell wall fraction with low mineral content improves burning characteristics (McLaughlin, 1996). To date our experience indicates that one and two cut systems provide the highest total yields, and these two management systems have produced similar average yields over the past two years.

Significant progress in characterizing switchgrass agronomically (Sanderson et al., 1996); physiologically (Wullschleger et al., 1996), phenologically (Redfern et al., 1996) and genetically (Gunter et al., 1996 and Hultquist et al., 1996) will help in developing breeding strategies to optimize desireable attributes for improved performance. In addition this program has developed new techniques for propagating switchgrass from tissue culture using a variety of tissue types (Denchev and Conger, 1995 and Alexandrova et al., 1996). These techniques are envisioned to provide important tools for rapid propagation of superior plants for focused breeding efforts designed to increase ultimate yield levels attainable and to improve yield stability by increasing switchgrass resistance to stress from climate, nutrition, and disease.

Economic and Demographic Issues - An important end product of the productivity research has been development of data bases on yield potential of energy crops across regions witin which they must compete with conventional cash crops. For switchgrass data on both yields attained in regional variety trials combined with data from fertilizer trials have been used to estimate costs of production by region as shown in Table 1. The economic data reflect the interplay of yields attained, land values, and crop management options which vary significantly across the 6 U.S. regions represented (Walsh, 1994).

Table 1 indicates that highest switchgrass productivity in the United States will likely occur in the Southeast, with its long growing season and in the corn belt, the original native range for the tall grass prairie. Production costs will likely be lowest in the Southeast and South plains.

Ultimately, the willingness of industry to locate a biofuels facility in a particular area will depend on what it must pay to buy the feedstock and transport it to the point of end use. Transportation costs will obviously vary with hauling distance, but are estimated to add $9-11 Mg^{-1} to the production costs of feedstocks, depending on the distribution of the supply region. Since these costs are so important to total production costs, an important research area in the ORNL BFDP efforts to assess regional potential to economically produce biomass crops has been demographic analysis of the interplay of available land, land quality, production potential, and production costs of competing crops (Graham et al., 1995). Those analyses suggest that US switchgrass supply potential could be as high as 140 billion liters of ethanol on 20 M ha of land and could provide profitability comparable to that of conventional crops (Graham et al., 1995).

FUTURE CONSIDERATIONS

On a national scale, biofuels presently contribute a relatively small proportion of the total energy use of the United States. Whether the potentially much larger role envisioned for biomass is realized or not will depend on how rapidly the potential for success can be demonstrated. Current demonstration projects with switchgrass in Iowa, alfalfa in Minnesota, and willow in New York will play an important role in establishing economic competitiveness of renewable fuels for generation of electric power. If these projects prove successful, it can be envisioned that political, economic, and public support for subsequent projects will be significantly enhanced.

A number of factors could significantly improve the chances of biofuels being more rapidly incorporated into the national energy stream. These include most particularly incentives that recognize the environmental benefits of energy crops for the regional and global ecology. Switchgrass, for example, has significant benefits to long term soil productivity and stabilitity. Where perennial grasses like switchgrass replace annual row crops, reduced erosion of topsoil, decreased chemical inputs of agrochemicals to streams and groundwater, and increased sequestration of carbon belowground are anticipated (McLaughlin et al., 1994).

While the corn to ethanol industry has led the way in production of renewable energy from agriculture and will continue to be an important contributor, there are important enviromental gains to made by relying increasingly on a perennial forage grass like switchgrass as the feedstock for future ethanol production. Because of its lower relative energy inputs and its high yields, we have calculated that switchgrass converted to ethanol by the SSF technology is significantly more energy efficient than ethanol produced from corn by conventional technology (Shapouri et al., 1995). These calculations involved developing energy budgets for energy inputs and outputs for both agricultural production and biomass conversion to ethanol. They indicate that ethanol produced from switchgrass can displace foreign oil at about 2.5 times the rate provided by corn. In addition, net reduction in CO_2 emissions is projected to be approximately 15-20 times more efficient with switchgrass than with corn [1].

The previous evaluation of the economics of biofuels production has been presented here without inclusion of subsidies. While a competitive biofuels industry without subsidies would be the most desireable endpoint, any factors that could increase the

[1] These calculations are included in an unpublished manuscript entitled "Power in prairie grasses: An economic and ecological perspective" by S.B. McLaughlin and M.E. Walsh to be submitted for publication later in 1997.

competitiveness of biofuels could accelerate their development and increase the benefits to the acricultural economy.

Subsidies might take the form of small end point price increases that could substantially increase prices that could be paid for biomass feedstocks. Our fuel prices are currently extremely low (by approximately 75%) by European standards so there is ample room for minor price adjustments upward that would fall within the relm of demonstrable consumer acceptance. A one cent per gallon increase in gasoline, could increase the price per ton paid for switchgrass by $1.00 if pure ethanol were the fuel and $20.00/ton if the fuel were a 5% blend.

Additionally the price of energy derived from fossil fuels may ultimatly be adjusted upward to reflect the true environmenetal and/or societal costs of these fuels. Increased resolve to reduce CO_2 emissions is occuring on a global scale and in some countries, such as Sweden and Denmark, has led to significant carbon taxes on fossil fuels. Such pricing patterns as well as the likely future increases in the purchase price of oil as world demand impinges on dwindling supplies, will ultimately make biofuels more profitable for producers and the energy industry.

A final form of subsidy, which could occur at no net cost to the consumer is the use of CRP land to provide biofuels (McLaughlin, 1994). The United States Department of Agriculture has considered and allowed variances in CRP permits that would allow annual harvest of perennial grasses such as switchgrass for energy use from lands under CRP contract. The concept of reducing CRP subsidies to allow the landowner to profit from sale of bioenergy feedstocks has the dual benefit of reducing Federal subsidies while increasing the potential profitability of feedstock production to the landowner. It is also unlikely that such a practice would measurably diminish the soil conservation functions of the CRP land since late harvests and residual stubble from harvest will retain the principal erosion control and soil building capacity of perennial grasses. This is particularly true when biomass removal by burning CRP fields is practiced, leaving less residue than harvesting.

CONCLUSIONS

The biofuels industry is still at an embryonic stage, but there are many reasons to be optimistic that this industry it can succeed with significant benefits to the agricultural economy, industry, and society. The US currently has an adequate land base to support a significant biofuels industry. Recent research indicates that biofuels, including specifically the forage grass switchgrass, can be produced on some of these lands at costs that are both competitive with cash crops and are within the range of acceptability as industrial feedstocks. Current research to improve biofuels productivity and to increase the efficiency of conversion of feedstocks to energy both as electric power and liquid fuels can be expected to improve the competitiveness of energy crops in both agricultural and industrial sectors. Generation of diverse chemical feedstocks from syngas produced from gasifying bioenergy feedstocks could further increase industrial support. Future trends in energy demand and valuation of the total societal costs of fossil fuels should provide additional impetus for expansion of biofuels markets. Perennial forage crops such as switchgrass should play a significant role in these markets because of their favorable energy returns, acceptability to the farming community, and soil conservation attributes.

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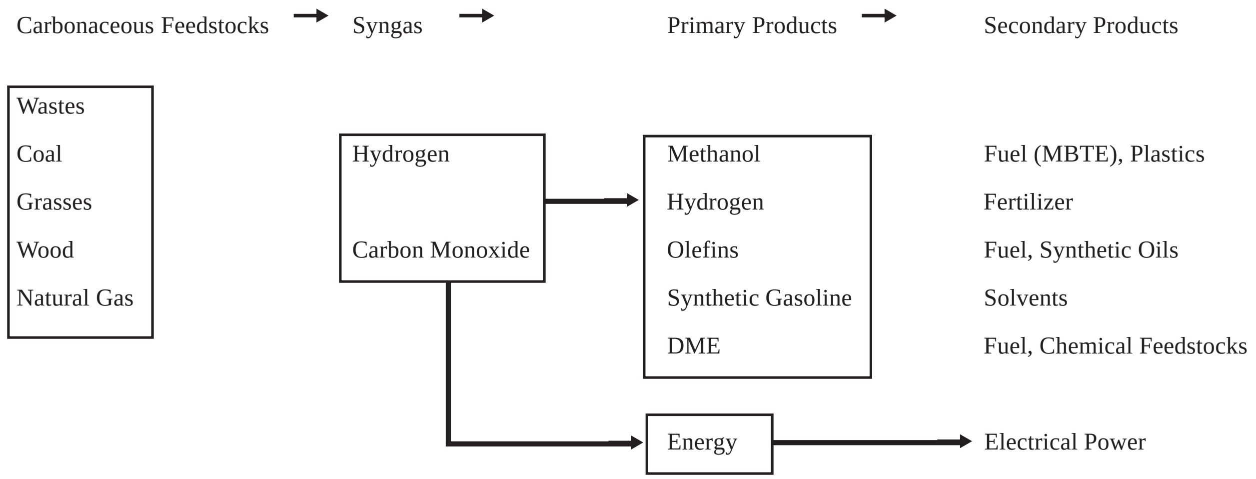
Figure 1
Gasification can use a wide variety of feedstocks to produce valuable and versatile primary and secondary chemicals useful in many industrial processes.[1]



[1] Abbreviations are MBTE (methy-butyl-tetra-ethyl) and DME (Dimethyl ether)

Table 1
Summary of Full Economic Costs[a] of Producing Switchgrass by Region ($\$\bullet ha^{-1}$, $\$\bullet Mg^{-1}$, $\$\bullet GJ^{-1}$)[b]

	Expected range of yields ($Mg\bullet ha^{-1}y^{-1}$)	Estimated average production costs ($\$\bullet ha^{-1}$)	Estimated costs ($\$\bullet Mg^{-1}$)	Estimated costs ($\$\bullet GJ^{-1}$)[c]
Lake States	6.7 - 11.2	452 - 531	67 - 47	3.69 - 2.60
Corn Belt	11.2 - 15.7	618 - 709	55 - 45	3.02 - 2.48
Southeast	13.4 - 20.2	474 - 622	35 - 31	1.93 - 1.69
Appalachia	6.7 - 13.4	393 - 504	58 - 37	3.21 - 2.06
North Plains	6.7 - 14.8	371 - 489	55 - 36	3.02 - 2.00
South Plains	9.0 - 15.7	375 - 536	43 - 34	2.36 - 1.88

[a] Full economic costs include variable cash costs (seeds, fertilizer, chemicals, fuel, repairs, etc.); fixed cash costs (interest, taxes and insurance); and the opportunity cost of owned resources (depreciation, non-land, capital, land, labor). Off-farm transportation costs are not included.

[b] The first number in each range corresponds to the lowest yield.

[c] Switchgrass is assumed to contain 15.75 MBtu per dry ton.

Figure 2
To evaluate and increase the potential of switchgrass as a bioenergy crop, new research was initiated in 1992 to explore ways to improve and maintain yields of switchgrass in the Southeastern and Southcentral United States. This collaborative research program involves research on breeding, tissue culture, physiology, and agronomic management of switchgrass production and now includes both collaborative test plots for germplasm evaluation and scale-up sites where larger scale switchgrass plantings are underway.