Switchgrass as a Bioenergy Crop

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Switchgrass is a native warm-season, perennial grass indigenous to the Central and North American tall-grass prairie into Canada. The plant is an immense biomass producer that can reach heights of 10 feet or more. Its high cellulosic content makes switchgrass a candidate for ethanol production as well as a combustion fuel source for power production. This publication discusses agricultural production aspects of switchgrass. Varieties, seed sources, crop establishment, management, and harvesting issues are presented. Ecological considerations are also discussed and a case study is presented along with references and further resources.

Contents

Photo courtesy of USDA NRCS.

Introduction

This publication details the production of switchgrass for use as a cellulose-to-ethanol and direct-combustion feedstock, and focuses on the agronomic and ecologic considerations of switchgrass production. Ethanol production is addressed in detail in the ATTRA publication *Ethanol Opportunities and Questions.*

Biofuels are carbon-based energy sources taken ultimately from solar energy as it is captured through photosynthesis and stored in plant tissue. Biofuels are renewable in that plants grow back after harvest, and can be regenerative when sustainable methods are employed to manage, harvest, and process the crops. Ethanol, used in gasoline (spark-plug) engines, is produced through the fermentation of plant sugars and distillation of the mash to produce fuel alcohol. Ethanol can be produced from crops such as corn and sugarcane, which are high in the sugars needed for fermentation, or from cellulosic materials, such as wood by-products and high-fiber grasses, such as switchgrass.

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Switchgrass can also be directly combusted or co-fired with coal to lower emissions associated with the burning of that fuel. However, for switchgrass to become practical as a directly combusted fuel in coal plants, retrofitting current boilers from coal or co-fired applications is required. For more information on this aspect of switchgrass, see the **Chariton Valley Biomass Project** case study below.

Switchgrass can be used as a fuel source to power ethanol plants, which results in reduced use of fossil fuels and contributes to a more positive energy balance for cellulosic ethanol.

Although recent news has been full of exciting reports about ethanol and switchgrass, producers need to be aware that a market for switchgrass as an energy crop is (in 2006) scarce to nonexistent. There is intense speculation about how, when, and whether these potential markets will materialize. In the meantime, corn ethanol is becoming more popular in the marketplace. In fact, 14 percent of the 2005 U.S. corn crop was used to produce ethanol, and the percentage is expected to grow. Cellulosic ethanol production is, from a processing and distribution standpoint, still in a research and development phase. As further research into cellulosic ethanol production and processing is completed, perhaps switchgrass can become a cost-effective, viable alternative energy source.

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Illustration courtesy of OSU Forage Information System.

Description, Range, and Adaptation

Switchgrass (*Panicum virgatum* L.) is a native warm-season, perennial grass indigenous to the Central and North American tall-grass prairie. It is found into Canada and ecotypes have been identified in regions from the Atlantic coast to the eastern Rocky Mountain front. Switchgrass is historically found in association with several other important native tall-grass prairie plants such as big bluestem, indiangrass, little bluestem, sideoats grama, eastern gamagrass, and various forbs (sunflowers, gayfeather, prairieclover, prairie coneflower). These widely adapted species once occupied millions of acres of tall-grass prairie. Now they are rarely seen, usually on land that cannot be utilized for annual cropping. Look for native plants like these in protected areas along fencelines, in riparian buffers, and especially in old cemeteries and church yards across the prairie states.

Switchgrass grows well in fine to coarse textured soils, and in regions where annual precipitation falls between 15 and 30 inches or more per year. It is an immense biomass producer, and can reach heights of 10 feet or more in wetter areas of the country. In general, ecotypical differences are related to local soil and climatic characteristics, with eastern and southern varieties adapted to higher moisture conditions, and western and northern varieties adapted to drier conditions.

Switchgrass Ecotypes and Varieties

As switchgrass evolved across North America, different ecotypes emerged with genetic and morphological characteristics that provide a good "fit" to a particular place. Thus ecotypes in the south typify southern characteristics, such as long season growth and subsequent high dry matter yield, given favorable growing conditions.

Two major types have emerged through natural selection. The upland types favor drier soils and fare better in semi-arid climates. The lowland varieties grow better in heavier soils and are found where water availability is more reliable. The lowland cultivars have the genetic ability to produce more dry matter than the upland cultivars.

Plant breeders at various Agriculture Research Stations from Texas to Nebraska have collected seeds from local switchgrass colonies and reproduced them into relatively uniform strains adapted to particular locales. These strains, once some bit of uniformity is achieved through artificial selection, are then registered as cultivars or varieties. This simple breeding program has created the many switchgrass varieties available today.

Upland Varieties	
Trailblazer	Developed by USDA-ARS and Nebraska Agricultural Research Division, Dept. of Agronomy, Univ. of Nebraska. Released 1984. Collections from natural grasslands in Nebraska and Kansas. Adapted to Central Great Plains and adjacent Midwestern states.
Blackwell	Developed by Plant Materials Center, NRCS, Manhattan, Kansas. Released 1944. Upland-type switchgrass. Widely adapted to Kansas, Oklahoma, southern Nebraska, and northern Texas in areas with 20 inches or more of annual precipitation.
Cave-in-Rock	Plant Materials Center, NRCS in cooperation with the Missouri AES. Released 1973. Tolerant to flooding. Adapted to Midwest.
Pathfinder	Selected at Nebraska AES, Lincoln, ARS cooperating. Released 1967. Winter-hardy, late maturing.
Caddo	Selected at Oklahoma AES, Stillwater, ARS cooperating. Released 1955. Forage yield under irrigation outstanding for native grass; recovers well after mowing.
Lowland Varieties	
Alamo	Developed by Texas Agricultural Experiment Station and NRCS, Knox City, Texas. Released 1978. A premier lowland variety, heavy yields especially in the south.
Kanlow	Developed at Kansas AES and ARS, Manhattan. Released 1963. Developed for soil conservation in poorly drained or frequently flooded sites.
Source: Oregon State University, 2006.	

Research studies have determined that selecting varieties based on location increases the survivability and productivity of a switchgrass stand. Parrish and Fike (2005) have found a "strong correlation between latitude of origin and yield," and "the main factor determining adaptation of a cultivar was its latitude of origin, with southern cultivars having higher yield potentials as they are moved north."

Switchgrass varieties should therefore be chosen based upon ecotype (whether an upland or lowland variety) and the latitude of origin. For instance, a high-yielding southern lowland variety like Alamo can potentially outproduce upland varieties in more northern latitudes. Check with your local Natural Resources Conservation Service (formerly SCS) or Cooperative Extension office for varieties adapted to your area.

Establishment, Management, and Harvest

Switchgrass has been successfully established by several well-known methods:

- conventional tillage and drill planting,
- no-till planting into crop stubble or pasture, including CRP, and
- frost seeding.

For successful biomass plantings, plant 4 to 10 pounds of switchgrass seed per acre at a depth of ¼ to ½ inch to obtain a plant

Seed Sources

Oregon State University's Forage Information System has seed source information on the varieties listed here and more. Some OSU variety fact sheets include seed source links to companies selling seed. See *http://forages.oregonstate.edu/main.cfm?PageID=172&SpecID=26* to access the Switchgrass fact sheet and seed sources.

You can also call your local Natural Resources Conservation Service or Cooperative Extension office to request recommendations of seed dealers in your area. NRCS and Extension phone numbers can be obtained in the Federal and County governments sections, respectively, of your local telephone directory. Also, you can access local NRCS and Extension directories on the following websites:

Natural Resources Conservation Service – *http://offices.sc.egov.usda.gov/locator/app?agency=nrcs*

Cooperative Extension Service – *www.csrees.usda.gov/Extension/index.html*

Photo courtesy of USDA NRCS.

density of greater than two plants per square foot. If drilled in rows, research suggests that wider spacings result in higher yields. Row widths as wide as 32 inches have been successful in establishing productive switchgrass stands.

Switchgrass can be no-till drilled into crop stubble or grass sod during the winter when the grass is dormant. Drills should be equipped with rollers or press-wheels to ensure adequate seed to soil contact. For germination and seedling survival, the soil should remain moist for at least one month to prevent desiccation and stand failure.

Frost seeding is the practice of broadcasting seeds during the early spring freeze-thaw period. The action of the soil freezing and thawing throughout the day works the seed into the soil, establishing seed to soil contact. Seed stratification is effectively accomplished with this method. Competition from existing perennial grasses can be severe in frost-seeded stands. Frost seeding without burn-down herbicides might work better in fields with some bare soil and little competition from aggressive perennials.

A word of caution. Planting switchgrass into cool soils can be problematic from a weed standpoint. Cool season weeds germinate first and can choke out switchgrass seedlings when the soil warms. If cool season weeds are a concern, consider no-till planting the switchgrass into a warmed soil with non-dormant seed. Switchgrass seedlings can compete better in warmer soils when on even footing with warm-season weeds.

A producer should expect slow switchgrass establishment even with non-dormant seed and good planting management. As with most native perennial grasses, switchgrass becomes fully productive only upon the third year after planting.

Seed Dormancy. Switchgrass seeds can be very dormant right out of the bag. A method to break dormancy ensures higher rates of germination. Without a dormancy-breaking step in the planting process, as few as five percent of the seeds may germinate. This is thought to be one reason so many switchgrass and other native warm-season plantings fail. To break dormancy, seeds can be wetted and held at 41 to 50 degrees F for one month, then carefully re-dried. This process is called *stratification* and is useful for small amounts of seeds. There is risk of causing heat damage to the seeds during drying, or causing premature germination of seeds, so small amounts should be used until you become familiar with the method.

Another dormancy-breaking method is to plant seed with a drill or no-till drill in winter or early spring. The cold temperatures the seed will experience will stratify them and help to break dormancy. Stratification can also be accomplished by frost-seeding in January to March. Again, care should be taken when planting switchgrass into cool soils due to cool-season weed pressure.

"After-ripening" is the dormancy-breaking practice of storing seeds in a warm environment for several years. When combined with no-till planting into a warm soil, it is one of the most effective methods for establishing weed-resistant switchgrass stands.

Weed Control. The establishment of warm-season grasses is difficult not only because of seed dormancy, but also because of competition from weeds. Perennial forbs and warm-season grasses such as crabgrass germinate in cooler soils and can have a severe impact on switchgrass stand establishment.

Switchgrass establishment can be improved by utilizing cultural and mechanical control measures to reduce weed pressure. For instance, annual cropping with small grains and field peas for one or two years will provide an opportunity to control weeds several times during the season while building soil organic matter. Also, nurse crops can sometimes reduce weed pressure and provide a cash crop in the form of hay, silage, or grain. Weeds can also be controlled in newly planted switchgrass stands by mowing two or three times during the growing season. Mow the weeds down to the tops of the switchgrass plants so as to reduce the impact of defoliation on the grass. Mowing can be effective against annual weeds especially as they mature but prior to seed set. Mowing can also reduce perennial weeds by effectively depleting root reserves by successive mowings when the plant is at the boot stage.

Fertility. Most research on switchgrass fertility has focused on its use as a forage. Grazing livestock require protein, and higher nitrogen (N) applications can ensure not only high yields but better quality feed. Some researchers have therefore considered nitrogen fertilizer recommendations for switchgrass to be much higher than necessary for biomass (i.e. cellulose) production.

Switchgrass, as a native perennial grass of the North American tall-grass prairie, evolved in symbiosis with many other ecological factors, including grazing, fire, nitrogen-fixing legumes and other forbs, and soil microorganisms including bacteria and fungi. Many scientists now believe that soil microbes play a major role in nutrient uptake. For example, micro-fungi (mycorrhizae) are thought to play an important role in phosphorus uptake. These microbes are a natural constituent in native grassland soils.

A review of the literature suggests that switchgrass can be grown on soils of moderate fertility without fertilizing, or with limited additions of fertilizer, and still maintain productivity (Parrish and Fike, 2005). Nitrogen and carbon naturally cycle from shoots to below-ground parts (roots) at the end of the growing season as a nutrient-conserving strategy. Prairie systems will gain nitrogen from the atmosphere at a rate of 2 to 10 pounds per acre per year. In addition, there is a reserve of nitrogen in the soil that can be mineralized and made available for plant growth. The addition of this nitrogen is a result of root death, leaf and stem death, and nutrient cycling from the urine and feces of grazing animals. Nitrogen-fixing legumes can also contribute to nitrogen availability in the range of 50 to 150 pounds per acre per year, depending on the species and percent composition of legumes in the field.

Switchgrass for biomass should be harvested once per year, in the winter. Under good management, a producer can expect a yield of 1 to 16 tons per acre. According to the Agricultural Research Service, yields in the Southeastern U.S. range from 7 to 16 tons per acre, and from 5 to 6 tons per acre in the western Corn Belt, while yields in the northern plains are typically more modest at 1 to 4 tons per acre (Comis, 2006). If the protein composition at harvest is 2 percent, and assuming a yield of 6 tons per acre, approximately 38 pounds of nitrogen are harvested per acre. This nitrogen must somehow be replaced or recycled to maintain productivity.

Switchgrass for biomass should be harvested once per year in the winter.

Nitrogen can be added into the switchgrass agroecosystem by (1) maintaining a legume component of at least 30 percent in the stand; (2) adding 2 to 3 tons of manure per acre broadcast after harvest; (3) incorporating manure in the fall prior to planting; or (4) using synthetic fertilizers judiciously. Incorporating legumes into a switchgrass stand can be problematic from an ethanol feedstock quality perspective, but not necessarily so if the biomass is dried and used in direct combustion. If synthetics are used, the producer should remember that low rates will provide excellent biomass yields. Yearly applications of no more that 50 pounds per acre should be appropriate.

It is very important to remember, though, that switchgrass has a remarkable ability to extract nitrogen from unfertilized soils. Parrish and Fike (2005) report a study where a field was harvested for seven years with no fertilizer applications, and averaged 53 pounds of N removed per year with one harvest per year. Clearly switchgrass, a native prairie grass, has the genetic ability to survive and produce with minimal if not zero inputs.

Companion Crops. Some farmers use companion or "nurse crops" in establishing perennial crops such as alfalfa and grass pastures and hayfields. An ideal nurse crop will grow more quickly than the crop it accompanies and will provide plant cover for the soil. Nurse crops must be removed early enough to allow the protected crop to grow unhindered. Nurse crops are often used on slopes to prevent water erosion and on level ground to prevent wind erosion and seedling desiccation. A nurse crop that has been used successfully in establishing switchgrass is sorghum-sudangrass. Sorghum-sudangrass is a warm-season annual grass that is used for grazing, hay, or silage. It is fast-growing in warm regions, broad-leaved, and of excellent forage quality when harvested at the right time, which is just around panicle emergence. Other companion crops to consider would be corn, spring planted wheat, triticale, or annual ryegrass. These crops could be planted early in the spring, followed by seeding of switchgrass between the rows. Plant switchgrass into companion crops prior to crop emergence or when growth is still low enough to permit a drill and packer wheels without damaging the crop.

Photo courtesy of USDA NRCS.

Harvesting. Switchgrass should be harvested with conventional haying equipment after the top growth has completely died back. This will occur from mid- to late October in most regions. Several studies have found that a single harvest of switchgrass from late fall or early winter results in the highest sustainable biomass yields and good stand persistence from year to year (Parrish and Fike, 2005). Moisture should be 15 percent or less to facilitate quick baling and transport, and to ensure a higher quality feedstock. Switchgrass that is co-fired in coal plants is burned at a moisture percentage of 12 to 13 percent. Contact the processing plant to determine the size of bale they will accept. Many research programs have utilized large rectangular bales (3 x 4 x 8 feet) with some success, as these are easier to transport than small squares. Be sure to leave about a 6-inch stubble after harvest. Forage research has shown that leaving stubble helps to trap snow, thereby protecting the root crowns from winter kill.

Ecological Considerations: Prairies and Farmscapes

Switchgrass, formerly a natural part of the prairie ecology of North America, may contribute to more stable agricultural systems. This assumes that switchgrass fields are inherently stable, beneficial to wildlife, and sufficiently productive to offer incentives to farmers to cultivate it. Switchgrass is deep-rooted, very efficient at using nitrogen, and is thought to maintain a symbiotic or beneficial relationship with microscopic soil fungi, which make soil nutrients available to the extensive switchgrass root system. Switchgrass is an excellent plant to use in riparian buffer strips or on other sensitive lands, as its root system prevents erosion while slowing the travel of surface water, decreasing run-off from agricultural fields, and allowing for greater water infiltration.

Annual cropping, such as is done with corn, soybeans, and small grains, results in loss of soil organic matter and release of soil carbon, whereas perennial crops can build soil organic matter and are thought to store more soil carbon due to the large amount of underground biomass they produce and maintain throughout the year.

Switchgrass is generally planted as a *monoculture* (a field planted to only one species, such as corn, alfalfa, or soybeans), either as a forage crop or a feedstock. Yield data have been developed by studying monoculture stands, and pure stands are thought to yield the highest quality feedstock for biofuels production (see **Feedstock Quality** section below). Monocultural production is thought to be problematic by many farmers and advocates of a more sustainable agriculture. Monocultures are generally not as resilient as *polycultures*, or fields planted to more than one species. Diverse plants occupy more niches and better use soil and water resources both above and below the soil surface. Biodiversity also provides food and cover for numerous beneficial organisms, from microbes to earthworms, to insects and small mammals. A diverse agricultural system mimics the complexity of nature, and fosters an ecological balance that some farmers have come to rely on to lessen the severity of pest problems as well as build soil fertility by allowing for natural nutrient cycling to occur.

The natural, native tall-grass prairie of North America was not, of course, a monoculture. Many grasses, legumes, forbs, and shrubs contributed to this complex and stable plant and animal community. This is important to remember, because a monoculture of switchgrass will never promise the same ecological benefits as a naturally diverse prairie. That being said, pure switchgrass stands still have significant benefits, especially for fields that have been cropped annually and are experiencing degradation due to erosion and depleted soil organic matter. A perennial grass stand offers nesting for birds, helps to sequester soil carbon, builds soil organic matter, and increases the efficiency of the water cycle. Since a switchgrass stand can have an effective lifespan of well over 15 years, it might find a place in long rotations to build soil and renovate infertile farmlands.

Prairie Polycultures for Biofuel Feedstock?

Switchgrass has been studied as a monoculture for the production of ethanol feedstock. One area that could possibly be studied by agronomists and agricultural engineers is the use of diverse prairie polycultures for biofuel production and their effect on ethanol feedstock quality. Another area to investigate would be the efficiency of polyculture feedstocks as a direct combustion fuel for energy generation, which could be especially useful for enhancing the sustainability of cellulosic ethanol plants.

Feedstock Quality

Producers who are experienced at growing grasses for livestock forage will find that producing switchgrass as an ethanol feedstock necessitates a management regime unlike that utilized to produce quality forages. High-quality ethanol feedstock is low in nitrogen content and high in cellulose. Cellulose is broken down either by an acid or enzymes into fermentable sugars prior to fermentation. Nitrogen reduces the conversion efficiency of fuels into energy and can become an air pollutant after combustion. Therefore, zero or low fertilizer nitrogen applications and a single yearly harvest after the plants have died back fully in the winter produce the best feedstock, as well as the highest amount of above-ground biomass, for ethanol production.

Economics and Multiple Uses of Switchgrass

The most important economic considerations in the production of switchgrass are (1) yield, (2) land costs, and (3) the prices of other feedstocks for biofuel production. Maintaining high yields and keeping costs low result in the best economic returns in recent switchgrass research projects. Another way to reduce costs and increase farm productivity is to consider multiple uses such as grazing and biomass production. Switchgrass is nutritious if grazed prior to the boot stage of development, and is used as a livestock forage by some

Case Study: The Chariton Valley Biomass Project

The Chariton Valley Biomass Project is a Chariton Valley RC&D managed project that is funded by the US Department of Energy, the US Department of Agriculture, and Alliant Energy, among others. In the spring of 2006 the project conducted a three-month test burn of switchgrass at a coal-fired station in Iowa, and has yielded some promising results.

The project involved over 31 thousand bales of Iowa-grown switchgrass, totaling more than 15 thousand tons of biomass fuel. The switchgrass fuel generated more than 19 million kilowatt hours of electricity, which can meet the electrical energy needs of more than 1,800 homes for one year. During the burn, sulfur emissions were reduced by 62 tons and CO2 was reduced by over 50 thousand tons. The switchgrass used in this test burn replaced over 12 thousand tons of Wyoming coal with a locally produced, renewable fuel.

Switchgrass can be co-fired in coal plants for electrical energy generation, or combusted in ethanol plants for the production of cellulosic ethanol. The Chariton Valley test burn exemplifies the applicability of this new technology, and helps us to focus on building greater efficiencies into renewable energy technologies, with the goal of making them cost effective, affordable, and sustainable.

Source: RenewableEnergyAccess.com

graziers from the South to the Midwest. In order to obtain both optimum livestock forage and biomass tonnage, graze the switchgrass to no less than 6 inches in the spring and or early summer, and allow the grass to regrow for a late fall or winter biomass harvest. Switchgrass stands tend to decline over the years with more frequent defoliation events (grazing, haying, or biomass harvest), so careful attention to timing of harvest, number of harvests, and regrowth is crucially important.

Switchgrass for biofuel production has been considered for use on Conservation Reserve Program (CRP) land in the more erodible regions of the tall-grass prairie states. Compared to annual cropping in these areas, switchgrass for biofuels could increase the ecological sustainability of the prairies while lowering the cost of the CRP program. However, CRP rules would have to be substantially modified to allow such an economic use of CRP lands. Consideration of the wildlife impacts of economic harvesting of CRP would also become an important consideration as an important part of the continued support for CRP has been its documented benefits to wildlife.

The CRP program is jointly administered by the USDA Farm Service Agency (FSA) and the Natural Resources and Conservation Service (NRCS), and once land is entered into the program there are limitations on how it can be used. Your local FSA or NRCS office can provide you with more information on CRP and the applicability of biomass production on CRP lands.

Researcher David Bransby's test plots of switchgrass at Auburn University have produced up to 15 tons of dry biomass per acre, with a six-year yield average of 11.5 tons per acre. Figuring roughly 100 gallons of ethanol produced per ton of feedstock, these switchgrass yields are enough to make 1,150 gallons of ethanol per acre each year (*Biofuels from Switchgrass: Greener Energy Pastures*, Oak Ridge National Laboratory, Tennessee). Corn ethanol feedstocks cost ethanol producers an estimated 40 to 53 cents per gallon of ethanol produced. Switchgrass feedstock costs per gallon of ethanol produced would need to be low enough (less than 40 cents per gallon) to at least compete with corn ethanol to make cellulosic ethanol production a cost-effective fuel. Currently, cellulosic feedstock costs per gallon of ethanol produced are much higher than for corn ethanol.

Cost Variables in Switchgrass Production

A short list of items to consider in calculating the cost of producing switchgrass…

- land – rent, land payments, taxes, opportunity cost
- establishment – fuel, seeds, tillage and planting equipment, weed control, fertility, labor
- crop maintenance – weed control, equipment repair, fertility, labor, etc.
- harvest – equipment, fuel, baling materials, labor
- transport – fuel, equipment, custom hauling, storage loss, labor

It is important to remember that the switchgrass market is still very immature, and much work needs to be done to understand the costs of conversions and development of local processing plants and marketing outlets. To learn more about marketing switchgrass for biofuel production, see the **Resources** section at the end of this paper.

Other Cellulosic Feedstocks

Switchgrass is not the only or possibly even the best biomass species for cellulosic ethanol production, but it does possess some ecological characteristics that make it a very good candidate. Among its positive qualities, switchgrass offers:

- pest and disease resistance,
- high yields of cellulose,
- low fertility needs,
- cultivars that are locally adapted and relatively available,
- excellent wildlife habitat,
- carbon sequestration in its extensive and very deep root system,
- tolerance of poor soils and wide variations of soil pH,
- drought and flood tolerance (depending on the ecotype and variety), and
- efficient water use in grassland ecosystems.

But many other perennial warm-season grasses may possess these same characteristics and more. What makes switchgrass particularly suitable as an ethanol feedstock? In research trials beginning in the mid-1980s, the Department of Energy began to seek plant species that would yield high quality and quantity biofuel feedstocks. Among the plants considered were reed canarygrass and switchgrass, among some other grasses and legumes. In the trials, switchgrass had the highest yields and breeding work was subsequently focused on switchgrass to the exclusion of the others.

Other sources of cellulosic feedstock under investigation are forest residue, wheat straw, corn stover (leaves, stalks and cobs), rice straw, and bagasse (sugar cane waste), other crop residues, municipal solid wastes, poplar, and willow trees. David Bransby of Auburn University suggests that, while ethanol will not be able to completely replace fossil fuels for transportation and electricity, the diversity of cellulosic feedstock materials available can go a long way to increasing our energy independence by making cellulosic ethanol more attainable. Coupled with conservation, biomass fuels can provide for a portion of U.S. energy needs.

Currently, cellulosic feedstock costs per gallon of ethanol produced are much higher than for corn ethanol.

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Notes

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This publication is available on the Web at:
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