

SWITCHGRASS: A POTENTIAL BIOMASS ENERGY CROP FOR ETHANOL PRODUCTION

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Abstract.

One of Canada's leading strategies for CO₂ reduction is the development of a biomass energy industry. Dedicated energy crops need to be used for the large scale, sustainable development of this industry. Switchgrass (*Panicum virgatum*) has been identified as the model herbaceous energy crop species by the United States Department of Energy. It is a warm season (C₄), perennial grass which is native to the southern Canadian prairies and Eastern Canada. Switchgrass has many characteristics which make it suitable for a biomass energy crop including: high productivity; low N, P and K requirements; high moisture use efficiency; stand longevity; soil restoring properties, disease and pest resistance; adaptation to marginal soils; and low cost of production. A cellulosic ethanol industry based on warm season grasses, unlike the grain ethanol industry, offers significant potential for CO₂ reduction. Energy crop production from C₄ perennial grasses will increase carbon storage compared to current land use by increasing above and below ground biomass and soil organic matter levels. CO₂ emissions will be reduced substantially compared to a fossil fuel based industry because switchgrass is a renewable feedstock with a high energy output/input ratio and because lignin (the byproduct of the cellulosic conversion) is used as an internal energy source for the conversion process.

INTRODUCTION

Using a complete material cycle analysis, Pimentel (1991) concluded that ethanol production from grain does not provide energy security, is not a renewable energy source, is uneconomical and increases environmental degradation. While other crops such as trees or perennial grasses are better than annual grains in terms of energy and the environment, the technology to economically convert these

materials into ethanol has been inadequate. However, recent advances in cellulosic conversion technology has made it possible to efficiently convert dedicated energy crops such as fast growing trees and warm season grasses into ethanol. With further investment in cellulosic conversion research it is anticipated that a cost competitive process with gasoline could be achieved by the end of the decade (Figure 1). The main processes in conversion of the cellulosic biomass are:

1. steam or chemical pretreatment (which breaks the lignin; bonds and makes carbohydrates available for enzymatic conversion);
2. enzymatic hydrolysis (converts the carbohydrates into fermentable sugars);
3. fermentation;
4. distillation;
5. residue processing (the lignin that is leftover after the extraction of ethanol is mechanically dewatered and burned to provide the steam and electricity to drive the entire conversion process).

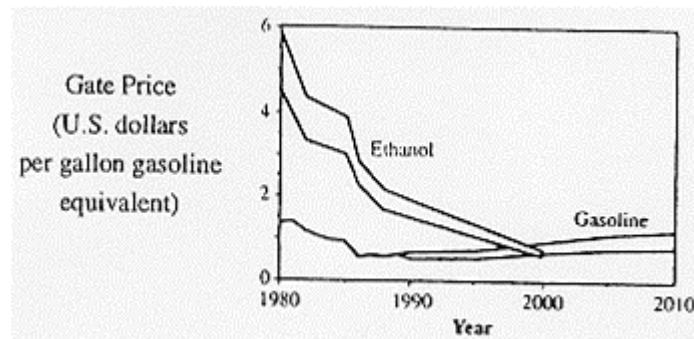


Figure 1. Past and projected costs (1988 basis) for ethanol and gasoline (Lynd et al. 1991). The range of future gasoline prices is based on U.S. Department of Energy oil gasoline price projections. For ethanol, prices are estimated from past research and an aggressive program for future research. The range shown arises from assumed capital recovery, with the higher values being for a capital recovery factor typical of private financing and the lower values being for a capital recovery factor more likely for municipal or utility financed structure.

Developing Low Cost Feedstocks

The recent advances in cellulosic conversion technologies is stimulating interest in low cost farm derived energy feedstocks. Crop production strategies need to be developed which are as efficient as possible in capturing sunlight (solar energy) and storing it in plants (solar battery). Focusing on energy efficiency will lead to low cost energy feedstock production. Desirable characteristics for energy feedstocks include:

1. Efficient conversion of sunlight (solar energy) into plant material (solar battery);
2. Efficient water use as moisture limitation is one of the primary factors limiting biomass production in most of North America;
3. Capture of sunlight for as much of the growing season as possible; source for birds.

The re-establishment of prairie grasses will improve water quality in several ways: annual grain crops responsible for increasing erosion potential will be replaced, ground water nitrate levels (Ramundo et al. 1992) and surface P loading (Sharpley and Smith 1991) will be reduced. Pesticide impacts on wildlife would be reduced because herbicides would be used probably only in the establishment year unlike the annual use of insecticides and herbicides in field crop production.

Table 1. Promising Warm Season Grasses for Biomass Production and their Native Soil Moisture Class (adapted from White and Madany in Illinois, 1981).

| Dry Prairie | Dry-Mesic Prairie | PrairieMesic | Wet-Mesic Prairie | Wet Prairie |
|------------------|-------------------|--------------|-------------------|-------------------|
| Sand Bluestem | Indian grass | Big Bluestem | Big Bluestem | Prairie Cordgrass |
| Little Bluestem | Little Bluestem | Indian grass | Indian Grass | |
| Prairie Sandreed | | | Switchgrass | |
| | | | Prairie Cordgrass | |

Other Promising Warm Season Grasses As Biomass Feedstocks

Switchgrass is only one of 1745 C4 grass species in the world that have been identified as suitable for growing in temperate climates (Stander 1989). In the U.S. alone there are over 300 C4 grass species (Stander 1989). Probably many of these other native and exotic C4 perennial grasses hold as much potential as switchgrass. However, if we view "nature as the standard" we should develop mixtures Of C4 grasses using plant materials from North America. The major advantage of switchgrass is that it is relatively inexpensive and easy to establish. However, other common tallgrass prairie species, such as big bluestem (*Andropogon gerardii*) and Indiangrass (*Sorghastrum nutans*), also have high levels of productivity (Gould and Dexter 1986, Stubbendieck and Nielsen 1989, Jung et al. 1990) and deserve significant research attention. 'Me seeding of all

three of the major tallgrass prairie species in mixtures rather than using a switchgrass monoculture may play an important role in reducing potential disease and insect problems if large scale biomass production occurs. In the higher rainfall areas of the prairie region, eastern gamagrass (*Tripsacum dactyloides*) has also proven to be very productive (Faix et al. 1980, Kaiser 1989) and may have a role in the implementation of low input, polyculture biomass systems.

In the native prairie, switchgrass is generally classified as a wet-mesic prairie species (Table 1). Other species are better adapted than switchgrass to the drier or wetter prairie conditions. For example prairie sandreed (*Calamovilfa longifolia*) has outyielded switchgrass in the dry regions of the northern U.S. Great Plains when 25- 35 cm of annual rainfall occurred

Wet Prairie

Prairie Cordgrass

(USDA 1989). As well, cold resistant, upland switchgrass ecotypes appear to be less adapted to wet prairie conditions than southern lowland switchgrass ecotypes. Using soil moisture as a classification system, we can get a good understanding of how switchgrass, as well as a number of other promising native warm season grasses, are adapted for biomass production (Table 1).

Compared to other warm season grasses, cold tolerance may limit switchgrass productivity. Prairie cordgrass (*Spartina pectinata*) has a more northern native range than switchgrass. Studies have identified a significant amount of chilling tolerance in prairie cordgrass which enables earlier canopy development (Long et al, 1990). However, published yield data is limited on this species. Nitrogen fertilization of native prairie cordgrass stands in Nova Scotia have produced yields of 7.7 t/ha (Nicholson and Langille 1965). Small plot biomass studies in England have produced yields of 8 to 23 t/ha (Long et al. 1990).

Canada's diverse climatic conditions will require a number of C4 species to be developed as biomass feedstocks. The natural range of prairie sandreed, switchgrass, and prairie cordgrass provide a good idea of how each of the three species has its own unique adaptation. A good starting point for a biomass plant material program in Canada would include these three species as well as big bluestem and Indiangrass which have a similar native range as switchgrass. Prairie ecologists could significantly contribute by collaborating with biomass researchers in developing species and mixtures for various climatic and soil conditions. Prairie ecologists are also uniquely connected to the best gene banks for prairie grasses, the existing prairie remnants. Collecting seed from a large number of productive species and accessions would also contribute to increasing diversity in biomass prairie plantings.

Using Biofuels For CO2 Abatement

The potential exists for warm season grasses as biofuel feedstocks to be one of the most important energy supply changes for reducing CO2 emissions. Energy production from warm season grasses changes CO2 emissions in two ways:

1. it displaces fossil fuels and their high CO2 emissions;
2. it returns the prairie landscape to a landuse that mimics more closely its original condition, thereby regaining a significant portion of the original carbon lost to the atmosphere through conversion of carbon rich soils to agricultural use.

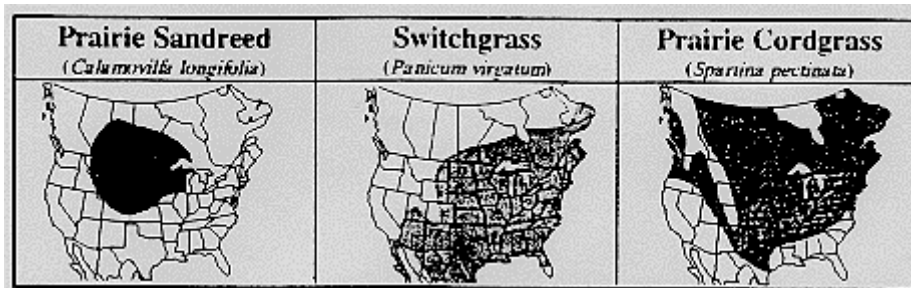


Figure 2. Native range of promising biomass feedstocks.

The production of cellulosic energy contributes a small amount of CO2 to the atmosphere but only to the extent that fossil fuels are used in their production. The vast majority of the CO2 released from the conversion of biomass is merely CO2 that has been sequestered from the atmosphere by plant growth - the carbon contained in the above and below ground biomass. In contrast, large amounts of CO2 released by fossil fuels are from long term carbon storage. The substitution of cellulosic energy crops for fossil fuels would thus result in a relatively large net reduction of atmospheric carbon dioxide (Turhollow and Perlack 1991).

Table 2. Relative CO2 emissions per unit of energy for various energy types.

| Energy Source | kg C/GJ Energy |
|---------------|----------------|
| Oilsands | 30.0 |

| | |
|-------------|------|
| Coal | 24.7 |
| Petroleum | 22.3 |
| Natural gas | 13.8 |
| Switchgrass | 1.9 |

From Hengeveld (1989) and Turhollow and Perlack (1991)

For Canada the greatest potential to reduce CO₂ emissions would come from using switchgrass or other cellulosic biomass crops as a replacement for gasoline derived from the oilsands projects (Table 2). There is no potential for the grain ethanol industry to reduce CO₂ emissions in an equally significant way. U.S. DOE studies indicate that corn ethanol produces 79% of the CO₂ emissions of gasoline (Marland and Turhollow 1990). If included in a 10% blend, this would reduce CO₂ emissions by 2.1 %. Any major reduction in CO₂ emissions from fossil fuels will only come from going beyond the 10% ethanol blend. Even if the grain ethanol industry had a significant potential to reduce CO₂ emissions it would be limited by both land base availability and by-product market saturation (making production costs prohibitive). The most significant difference in reducing CO₂ emissions between switchgrass and grain ethanol comes from by-product utilization of the two processes. In the switchgrass ethanol cycle, lignin is the byproduct which can be burned to provide sufficient steam and electricity to complete the entire conversion process. In the grain ethanol cycle, fossil fuel is used for the conversion process and the by-product (distilled grain) is used in an intensive beef feedlot industry. The most recent analysis of the cellulosic ethanol fuel cycle indicates a 91 % reduction in CO₂ emissions compared to reformulated gasoline and 4.35 units of output energy are produced for each unit of fossil energy required (Bull et al. 1992).

SUMMARY

Switchgrass is a resource efficient, native, perennial grass which has significant potential as a feedstock for the development of a cellulosic ethanol industry in Canada. It could play a major role in reducing Canadian CO₂ emissions by 1) increasing carbon storage in soil and vegetation compared to present land use and 2) enabling the production of a liquid transportation fuel that will reduce CO₂ emissions by approximately 90% compared to gasoline. The development of this industry could play an important role in helping Canada solve some of its most important problems including job creation, energy security and global warming.

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