

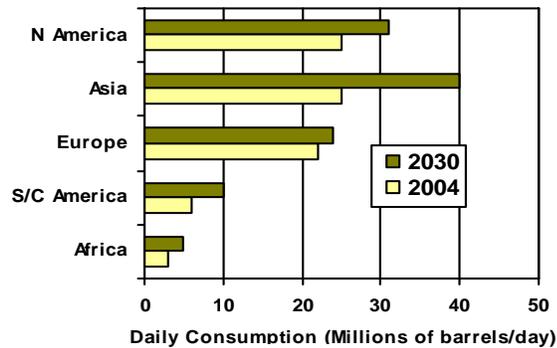
THE FUTURE OF ALFALFA AS A BIOFUELS FEEDSTOCK

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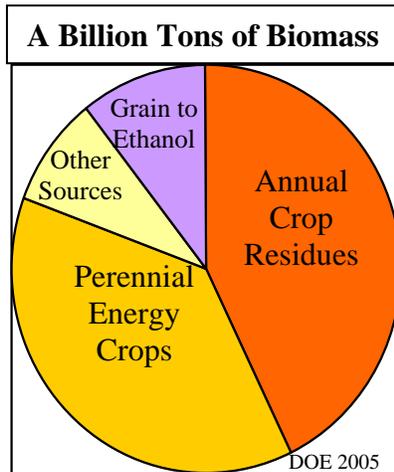
THE CASE FOR BIOFUELS

Global energy demand is increasing and known global petroleum supplies are decreasing. In 2005 the U.S. consumed 20.8M barrels/day of petroleum, 60% of which was supplied by oil imports. Almost half of the imported oil comes from parts of the world where an unstable political environment increases future supply risk. Alternative sources of liquid fuel will be required to provide U.S. energy security and to protect environmental quality and economic vitality.

World Petroleum Consumption by Region



Source: EIA 2004, 2007



Biofuels have been heralded as a renewable, cost effective alternative to petroleum-based liquid fuels. Although a corn-based ethanol industry has grown very rapidly in the U.S., most experts see the need for the development of a cellulosic-based biofuels industry to meet the current the Federal biofuels mandate for displacing 30% of petroleum consumption by 2030. In 2005 the U.S. Department of Energy (DOE) and USDA concluded that a billion tons of biomass would be needed to produce the required alternative fuels. In what is now commonly called the “Billion Ton Report”, a detailed plan called for 377M tons (55M acres) of perennial dedicated energy crop production to support the billion ton goal (Perlack et.al. 2005).

The Bush Administration recently outlined a portfolio of recommended technologies and processes for the production of biofuels, focusing on improved efficiency of feedstock conversion. The plan also states that a significant portion of the nation’s 2017 energy supply, especially transportation fuel, will come from conversion of biomass feedstock to liquid fuels. The current food vs. fuel debate also holds promise for the future of ligno- cellulose energy crops. The 2007 Energy Bill includes specific incentives for cellulosic ethanol production.

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THE CASE FOR ALFALFA

Corn stover, corn cobs, and wheat straw are obvious annual crop residue feedstocks for cellulosic ethanol production. Switchgrass, a native C4 perennial forage grass, is often mentioned as a leading perennial energy crop candidate. Drought tolerance, low fertility requirements, and ability to grow on marginal soils, will likely make switchgrass an important component in biofuels cropping systems in some regions. How about alfalfa? Should alfalfa be a significant component in cropping systems dedicated to production of biofuels feedstock?

Environmental benefits. As a deep rooted perennial plant alfalfa has several documented environmental benefits in cropping systems. Reduced surface erosion and nutrient leaching both potentially benefit water quality compared with annual crops. The unique N-fixation system in which roots take up available soil nitrate before expending energy for N-fixation, makes alfalfa a scavenger for excess soil nitrates left behind from preceding annual crop such as corn; reducing potential ground water contamination. Alfalfa's extensive, deep and penetrating root system improves soil tilth and increases carbon sequestration compared to annual cropping systems. This combined with the fact that alfalfa is a legume and leaves behind a nitrogen credit for the succeeding crop gives alfalfa growers some bragging rights: alfalfa is one of the few crops that results in a net improvement of the soil resource.

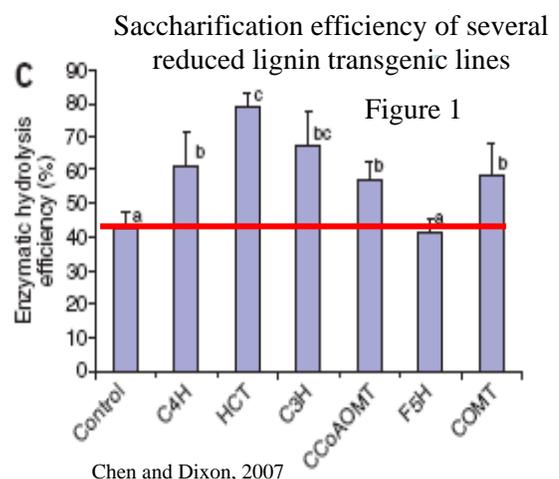
Nitrogen Fixation and Rotational benefits. Growers have long recognized alfalfa for high yield of high quality forage, but also realize the benefits of alfalfa in crop rotations. Alfalfa not only produces more protein per acre than any other U.S. crop, but the residual nitrogen credits for alfalfa, when contributed to subsequent crops in rotation, far exceed those of other legume crops. As energy prices climb, so does the price of nitrogen fertilizer ... and the value and benefits of nitrogen credits from alfalfa will also rise. In the first year and second year following alfalfa stand takeout, the succeeding crop receives a nitrogen credit of approximately 150lbs/A and 100lbs/A respectively (2006 ISU Nitrogen Fertilizer Recommendation for Corn in Iowa). The University of Illinois estimated that in 2005 nitrogen costs represented 22% of total input costs for corn grain production. Alfalfa in crop rotations will decrease N-fertilizer costs and increase the energy balance (i.e. energy in vs. energy out) of almost every biofuels cropping system. Other crop rotation benefits, due to factors such as improved soil tilth, have also been documented.

Leaves vs Stems. Alfalfa hay is generally composed of about an equal proportion of leaves and stems. The leaves are highly digestible, high in protein, with a minimal drop in quality over a wide range of plant maturity. The stems are high in fiber, less digestible, and lose quality rapidly with advancing maturity, primarily due to the lignification of cell walls. Researchers at the University of Wisconsin and the U.S. Dairy Forage Research Center (USDFRC) have developed a prototype one pass forage harvester that separates leaves from stems (Shinners et. al. 2007). This engineering breakthrough would allow alfalfa producers to harvest a high quality leaf fraction for animal feed, and a high ligno-cellulose stem fraction for use as a biofuel feedstock. The ability to harvest a high value leaf "co-product" will make alfalfa a competitive biofuel feedstock.

Knowledge and Infrastructure. Alfalfa is currently planted on about 24 million acres in the U.S. Several decades of agronomic research inform public and private agronomists, who in turn, effectively support several thousand professional alfalfa forage producers. There is a healthy alfalfa seed industry and a few thousand expert alfalfa seed growers producing alfalfa seed on over 100,000 acres each year. Industry is investing approximately \$10M/yr in alfalfa breeding research, and over 200 commercial varieties are currently on the market. Biotechnology methods have been successfully applied to alfalfa, making it an excellent target for potential improvement via genetic engineering. Switchgrass, Miscanthus, willow and most of the other perennial plants frequently mentioned as potential candidates for dedicated energy crops currently have little to none of the infrastructure required for wide-scale commercialization.

Economics. In early discussions at the DOE alfalfa was discussed and dismissed as a potential candidate for biofuels feedstock. The reasoning was simple – it’s worth too much as an animal feed. What’s different now? First, new technology to separate, at harvest, leaves from stems increases the potential per/acre income for alfalfa growers. The co-products bring two distinct sources of income – feed *and* fuel. Secondly, increasing energy prices have and will continue to increase the cost of nitrogen fertilizer. To increase energy balance in biofuels cropping systems, legumes will need to be part of the rotation. Unfortunately, scientists are just beginning to examine net energy balance and economic return per acre in mixed cropping systems. In unpublished research at the USDFRC and the University of Wisconsin, a two year “biofuels” rotation of alfalfa-corn vs corn-corn increased the efficiency of energy production by 25%, but decreased energy yield/A by 13%. Although it is difficult to predict what government incentives might look like to promote the production of perennial energy crops for cellulosic fermentation, farmer credits for carbon sequestration and processor credits for ethanol produced from non-grain sources are often discussed.

New technology and new traits. The Consortium for Alfalfa Improvement (CAI)² is a cross institutional collaboration focusing on using biotech tools for improving alfalfa for dairy and biofuels feedstock. Lignin reduction to increase fiber digestibility has been a key CAI research focus. Reduced lignin transgenic plants have been in field testing since 2001, and in 2007 were used in “proof of concept” feeding studies conducted with both young lambs and dairy cows. Researchers at the Noble Foundation evaluated several reduced lignin genotypes for efficiency of conversion to sugars using a standard cellulosic fermentation protocol (Chen and Dixon, 2007). In this study several of the transgenic reduced lignin genotypes showed >50% increase in sugar yield (Figure 1). This study strongly suggests that reduced lignin alfalfa genotypes, currently in early commercial development for improved forage quality for dairy cows, will also have a higher ethanol yield



² The Consortium for Alfalfa Improvement member organizations are Forage Genetics Intl., The Samuel Roberts Noble Foundation, Pioneer HiBred Intl., and the U.S. Dairy Forage Research Center.

compared to standard alfalfa types. New transgenes conferring increased drought tolerance, increased biomass and improved protein quality are also being evaluated and will also likely have applications for both dairy and biofuels uses.

SUMMARY

The current DOE/USDA goals for biomass production supporting cellulosic ethanol production will require a variety of crop species and cropping systems that are regionally adapted. There will be clear benefits for a perennial legume in many of these cropping systems, and alfalfa is ideally suited for this use. Recent technological breakthroughs in harvesting technology and lignin modification further enhance the potential of alfalfa as a key biofuel feedstock. A sustainable production system for bioenergy crops will need to make sense from both an economic and environmental standpoint. Alfalfa has the potential to deliver on both fronts.

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