Bioenergy and Energy Alternatives National Program
FY2004 Annual Report

Introduction

Research is conducted under this national program to develop technology that will create jobs and economic activity in America, improve energy security by reducing the Nation's dependence on foreign oil, and improve the environment by developing alternate energy sources and increasing the use of agricultural crops as feedstocks for biofuels.

Selected Accomplishments by National Program Component for Fiscal Year 2004

Ethanol

Safer process developed to obtain corn oil. Currently, extracting corn germ with hexane produces all corn oil. Hexane is a flammable and toxic solvent and the safety and environmental issues associated with its industrial use are very expensive. Others have suggested that an extraction method based on water and enzymes could be used to extract corn and other vegetable oils but no one has been successful at developing an economically viable process. Scientists with the Crop Conversion Science and Engineering Unit at the Eastern Regional Research Center in Wyndmoor, Pennsylvania, developed an aqueous enzymatic process to extract corn oil from oven dried corn germ from wet milling. This process extracted greater than 90% of the oil in the germ and did so without use of hazardous or environmentally harmful materials.

Making barley a better feedstock for fuel ethanol. The presence in barley of a material called beta-glucan limits the use of barley for fuel ethanol production. Scientists with the Crop Conversion Science and Engineering Unit at the Eastern Regional Research Center in Wyndmoor, Pennsylvania, were able to select enzymes that convert over 70% of the beta-glucan into fermentable glucose sugars. In a commercial fuel ethanol plant this would increase ethanol production by up to 4%, enough to mean the difference between economic failure and profitability.

Fewer enzymes needed for wet milling of corn. It has previously been demonstrated by ARS scientists at the Crop Conversion Science and Engineering Unit at the Eastern Regional Research Center in Wyndmoor, Pennsylvania, that enzymes can replace hazardous sulfur dioxide in wet milling of corn. However, enzyme cost has been a major hurdle to commercialization. The ARS research team has now optimized the process such that enzyme use has been reduced by a factor of ten with production similar to that of conventional wet milling. These developments enhance the chances of commercializing this environmentally favorable processing technology.

Yeasts more tolerant to toxic byproducts of biomass hydrolysis. Furfural and hydroxymethylfurfural (HMF) are key toxic byproducts of the dilute acid hydrolysis of lignocellulosic biomass, the most economical method of releasing sugars for fermentation to ethanol biofuel. The lack of yeasts able to tolerate these toxic byproducts is a significant factor limiting commercial-scale biomass to ethanol conversion in the United States. Researchers with the ARS National Center for Agricultural Utilization Research in Peoria, Illinois, have described an adaptive response of yeasts to these fermentation inhibitors. Strains adapted to the presence of furfural and HMF was shown to be able to convert these compounds to other forms, likely to be less toxic. These findings provide important groundwork and guidelines for the further development of industrial yeasts capable of in situ detoxification of HMF and furfural as a means of alleviating these stress factors in commercial dilute acid hydrolysates of lignocellulosic biomass.

<u>Pilot-scale demonstration of corn fiber conversion to ethanol:</u> Conversion of corn fiber could increase the yield of ethanol from a bushel of corn by 10%. A successful collaboration among a university, an ethanol producer, ARS scientists (Fermentation Biotechnology Research Unit, National Center for Agricultural Utilization Research, Peoria, Illinois), and the U.S. Department of Energy demonstrated at pilot plant scale (43 gallons permit of slurry) the fermentation of corn fiber into ethanol. The process used recombinant Escherichia coli strains developed by ARS. In particular, E. coli FBR16, which has been engineered to co-ferment arabinose, glucose, and xylose sugars, had ethanol yields that were 84-97% of the maximum possible based upon beginning sugar concentrations. The results demonstrate the ability of the developed strains to ferment hydrolysates generated by industrially sized hydrolysis processes.

<u>Improved enzymes for conversion of cellulosic biomass to ethanol:</u> Inexpensive sugars are critical to producing attractive, competitive biofuels and biobased chemicals from plentiful resources such as straws, grain middlings, corn fibers, and other crop residues, however, chemical, capital and energy costs prohibit application of the required acid hydrolysis, and conventional enzymes are not nearly efficient enough to be cost-competitive and discovery of new enzymes with extended stability and activity properties are crucial to reducing these costs. Scientists and engineers with the Biobased Chemistry and Engineering Research Unit at the Western Regional Research Center, in Albany, California, identified and developed appropriate enzymes for break-down of lignocellulosic materials. Genes of xylanolytic enzymes that can efficiently degrade hemicellulose were screened and a number of genes that encode xylan-degrading enzymes (xylanaeses and b-xylosidases) have been isolated from genomes of environmental microbial sources as well as pure bacterial isolates. These genes have been cloned and biochemically characterized by producing proteins via a bacterial expression system. Research will improve the utilization of biomass to make ethanol or specialty chemicals from rice straw, wheat straw, grasses, and other under-utilized agricultural byproducts.

Biodiesel

<u>Improving the economics of a new method to produce biodiesel.</u> If the process of extracting oil from oilseeds could be eliminated the cost of biodiesel could potentially be reduced. ARS scientists with the Fats, Oils and Animal Coproducts Research Unit at the Eastern Regional Research Center (ERRC) in Wyndmoor, Pennsylvania, had previously developed and conducted initial performance analyses of a simple chemical method, termed in situ transesterification, which allows the direct use of intact oilseeds as a source for biodiesel production. In collaboration with ERRC's Cost Engineer, project researchers now have constructed a

quantitative computer model and performed an economic analysis to estimate the cost of biodiesel production. This analysis showed that the new method had substantially higher predicted process costs than did traditional biodiesel production methods. The analysis, however, clearly indicated the cause of the increased costs. Through subsequent research, the researchers have successfully modified the original protocol and reduced the cost of that operation. The findings are a significant advance in the effort to reduce the cost of biodiesel production.

Combinations of antioxidants improve biodiesel stability. Biodiesel, like many products made from vegetable oils, has relatively poor stability when in contact with air and oxidative degradation of biodiesel during storage can negatively impact fuel quality. ARS scientists with the Food and Industrial Oil Research Unit at the National Center for Agricultural Utilization Research in Peoria, Illinois, found that when treated with a combination of two antioxidants, methyl soyate stability was improved to a degree that exceeded the effect of either antioxidant acting by itself. Combining two synergistic antioxidants will lower costs of biodiesel by reducing the quantity of antioxidant necessary to protect it from oxidative degradation.

Energy Alternatives for Rural Practices

Demonstration of economical method for remote pumping of water: Mechanical windmills have predominantly been used to pump water from deep wells (200-600ft), but most are over four decades old and the mechanical windmill piston pump requires considerable maintenance. Engineers with the Renewable Energy and Manure Management Research Unit at Bushland, Texas, demonstrated that a relatively new submersible positive displacement pump powered by wind or solar energy can provide sufficient water from a deep well for 100 cattle. It was found that wind or solar energy systems that provide 0.5 – 1.0 kW of electric power are adequate for use of this style of pump in this application. This remote water supply system requires little maintenance and is more economical for farmers and ranchers than use of a conventional mechanical windmill.

Energy Crops

More fuel ethanol from switchgrass than from corn. Economic production of biofuels requires production of feedstocks that produce large yields. ARS scientists at the Wheat, Sorghum and Forage Research Unit, Lincoln, Nebraska, found that for marginal cropland in the western Corn Belt, perennial biomass crops such as switchgrass have the potential to produce more ethanol per acre than corn while providing environmental benefits similar that of the Conservation Reserve Program. Four year average ethanol yields were 450 gallons per acre. These findings show that large quantities of ethanol producing crops can be grown while avoiding soil erosion and protecting soil quality.

Successful genetic modification of switchgrass. Improved efficiency of biomass utilization through improved crop genetics is critical for the production of renewable fuels from plant biomass. Scientists with the Genomics and Gene Discovery Research Unit at the Western Regional Research Center in Albany, California, have successfully genetically modified switchgrass, an herbaceous energy crop, by Agrobacterium mediated transformation. Plants have been regenerated that contain sequences designed to down-regulate lignin biosynthetic enzymes. Some of these plants could provide material that is more readily converted to ethanol by existing technologies, and also provide higher quality forage for grazing livestock, thereby improving meat and dairy production.

Hybrid cultivars increase biomass yield of switchgrass. For crops to play a significant role in producing energy, biomass yields must be increased. ARS researchers with the Wheat, Sorghum and Forage Research Unit in Lincoln, Nebraska, demonstrated the feasibility of using hybrid cultivars to increase switchgrass biomass yield for use as a bioenergy feedstock. F1 hybrid populations of the cultivars Kanlow x Summer produced 24% higher biomass yield than Kanlow and 50% greater yields than Summer in sward plots in eastern Nebraska in 2002 and 2003. The F1 hybrid populations produced 20 Mg/ha of biomass during years with below average precipitation. The findings show the potential for increasing biomass yields of switchgrass by the development of hybrid cultivars.