FY 2007 Annual Report
NP307-- Bioenergy and Energy Alternatives

The sustainable availability of large volumes of biofuels to meet the Nation's need for domestically-sourced, renewable transportation fuels is the major driver behind ARS' research in bioenergy. Consequently, supporting research that enables the continued growth in the two commercial biofuels – ethanol and biodiesel – is a priority for the ARS National Program in Bioenergy and Energy Alternatives. In addition, special cellulosic energy crops, such as switchgrass, that can be cultivated on lands unsuitable for corn or soybeans, could significantly increase the amount of ethanol that could be domestically produced without disrupting traditional markets for food or feed. Therefore, another major component of NP307 focuses on energy crops. Finally, in order to provide farmers and ranchers with power that is affordable and has relatively fixed costs, NP307 also funds research that brings alternative sources of energy, such as wind and solar, to rural America.

The NP307 Action Plan is being revised as a consequence of the normal, five-year cycle in ARS National Programs. Therefore, accomplishments listed in next year's (FY 2008) Annual Report will be categorized according to components associated with the new Action Plan:

- Feedstock Development
- Feedstock Production
- Conversion and Co-Products

A comprehensive collection of the accomplishments by the Bioenergy and Energy Alternatives National Program over the last five years has been published; the NP307 Accomplishments Report is posted on the ARS website at www.ars.usda.gov/SP2UserFiles/Program/307/NP307AccomplishmentReportFinal-web.pdf.

Component I: Ethanol

Economics and Energy-Efficiency of Different Bioenergy Production Systems: ARS assessed the economics and energy-efficiency of ethanol production from three crop systems in the Upper Midwest: continuous corn, continuous switchgrass, and an alfalfa-corn rotation. Results show alfalfa-corn could maximize farm income and is energy-efficient in comparison to continuous corn or switchgrass.

Amount of straw residue available in Northwest for bioenergy production: For every county in Oregon, Washington and Idaho, ARS scientists determined the amount of straw production that should be returned to the soil for conservation purposes. A resource map indicating how much excess straw was available for conversion to bioenergy was also developed. In aggregate, ARS found that over seven million tons of straw are available for biorefining annually in this region. [this research was funded through NP207]

Assessing potential adverse effects of crop residue removal on sustainability: A long-term field study by ARS scientists from Lincoln, NE compared carbon sequestration by switchgrass (managed as a biomass energy crop) with non-irrigation, no-till corn (where both the grain and stover are harvested for biomass energy). In the first five years of the study, removal of half the stover significantly reduced corn yields. Over the same time period, the ethanol yield from switchgrass would have been equal or greater than the combined ethanol yield from corn grain and harvested stover. As a result of this and other research, DOE and USDA now recognize that sustainability is a major issue in the use of crop residues for bioenergy, and new research initiatives on stover removal and sustainability are in progress.

More Efficient Oil Extraction Process for Corn Oil: Most corn-to-ethanol biorefineries are based on dry milling; and almost all dry mill corn refineries use hexane, a hazardous organic solvent, to extract corn oil as a co-product. A new, solvent-free, aqueous process utilizing a protease (a protein-degrading enzyme) and a cellulase to extract the corn oil was developed by ARS. The process recovers 80-90% of the oil and does not require heat. With commercial production of cellulosic ethanol and decreasing cost of cellulase enzymes, this enzymatic extraction process will become cost competitive with hexane extraction.

New Corn Oil with Health-Promoting Nutraceuticals: Most corn-to-ethanol biorefineries are based on dry milling; and almost all dry mill corn refineries use hexane, a hazardous organic solvent, to extract the oil-rich corn germ as a co-product. By utilizing ethanol rather than hexane, ARS produced an oil containing levels of lutein and zeaxanthin (beneficial phytonutrients) ~100 times higher than commercial corn oil. At these levels, a mere two tablespoons per day of the ethanol-extracted corn oil should slow the progression of age-related macular degeneration. Because of the significant health benefits, such an oil should sell for a higher price, thus returning more coproduct value to the producer.

Barley Fractionation Process: Barley grain, a promising feedstock for ethanol production in regions outside the corn belt, contains oil that is extremely rich in valuable and health-promoting phytosterols, tocotrienols, and tocopherols. ARS developed a barley fractionation process that yields oil-rich small kernel fragments and larger starch-rich fragments for fuel ethanol production. Being able to produce nutraceutical-rich barley oil as a co-product will improve the profitability of a barley-to-ethanol biorefinery.

Biobutanol from Wheat Straw: ARS developed an energy-efficient process for converting wheat straw to butanol. After a dilute-acid pretreatment, wheat straw was enzymatically saccharified and simultaneously fermented to butanol. The process does not require a post-pretreatment detoxification step, thus resulting in significant cost savings. Further, gas-stripping the fermentation broth to remove butanol avoided product inhibition of the fermentation and maintained high rates of butanol production. The integrated saccharification, fermentation, and recovery process (SSFR) significantly reduces the cost of producing butanol from lignocellulosic feedstock.

DDGS Pellets: ARS developed a process for pelleting distillers dried grains with solubles (DDGS) on a commercial scale. Utilizing traditional feed milling equipment, high quality pellets were produced without the use of binders and without affecting nutrient composition. Additionally, pelleting significantly increased the bulk density of DDGS (from 9.1 to 20.1%) and decreased the angle of repose (from 18.3 to 19.2%) thereby increasing DDGS flowability, a major issue in DDGS storage and transport. In addition to increasing the value of DDGS to the feedlot industry, pelleting could expand DDGS use into rangeland settings.

DDGS in Aquaculture Feed: Distillers dried grains with solubles (DDGS) could be an inexpensive protein source in aquaculture, but use of DDGS in fish feed has been hampered by its low starch and high protein & fiber content. In collaboration with South Dakota State University (SDSU), ARS developed balanced feed rations for tilapia consisting primarily of DDGS (up to 60%), soy meal and corn flour. The pelleted feeds had excellent nutritional and physical properties, including floatability; and the level of expensive fish meal required for these formulations was only 6%. A production-scale feeding trial is currently underway at SDSU.

Component II: Biodiesel

Biodiesel from Inexpensive Grease: Most biodiesel, a renewable and biodegradable diesel fuel, is produced from refined vegetable oils. However, the high cost of these oils can make biodiesel production unprofitable. Greases are lower-cost feedstocks, but their high free fatty acid (FFA) content makes them difficult to use in a conventional biodiesel plant. In collaboraton with a university partner, ARS developed immobilized acid catalysts that are highly efficient in esterifying FFAs to biodiesel. This novel technology will expand the production of biodiesel fuels from greases and other inexpensive, second-use fats and oils.

Glycerol-based Plastics: Glycerol, a co-product of biodiesel production, continues to drop in price as biodiesel volumes increase and traditional markets for glycerol become highly saturated. To create new, value-added markets for glycerol, ARS developed a variety of polyesters by reacting glycerol with adipic, azelaic, suberic, and sebacic acids. The resulting polymers are biodegradable and can be used as weed barriers and for controlled-release of fertilizers or pesticides. Glycerol polyesters could replace common petrochemical polymers such as polyethylene or polypropylene.

Component III: Energy Alternatives for Rural Practices

New Rotor Blade Design Improves Performance Of Small Wind Turbines: Because of inefficient blade designs, wind-electric water pumping systems are not effective for watering livestock in summer months due to low winds. ARS scientists designed, built and tested blades exhibiting better low-wind efficiencies. The ARS-designed blades doubled the amount of water pumped, thereby allowing wind-electric pumping systems both to perform as well as mechanical wind mills during low-wind periods and to generate excess electricity during high-wind periods.

Component IV: Energy Crops

Improving the photosynthetic efficiency of plants: All energy crops convert sunlight into plant matter which is subsequently converted into bioenergy. Consequently, increasing the photosynthetic efficiency of plants will benefit bioenergy production. The rate-limiting chemical reaction in plants for the conversion of sunlight is the fixation of carbon dioxide, a step catalyzed by the RUBISCO enzyme (ribulose-1,5-biphosphate carboxylase/oxygenase). Further, at moderately high temperatures, an enzyme that activates RUBISCO loses its "activase" ability; and as a result, RUBISCO's activity declines significantly. ARS researchers at Urbana, IL, developed a more thermostable activase enzyme for Arabidopsis (a model plant) by inserting a portion of a more thermostable activase from tobacco. The initial results indicate that the rate of photosynthesis at moderately high temperatures as measured by gas exchange is improved in the transgenic lines and that the recovery of photosynthesis is faster when the plants are returned to a lower temperature. Scientists will use the information gained from this "proof of concept" research to try to improve the photosynthetic efficiency of energy crops. [this research was funded through NP302]

Diploid switchgrass identified: Identifying beneficial genes and gene combinations for bioenergy production is quite difficult in complex, polyploid genomes such as switchgrass. Fortunately, ARS identified a diploid variety of switchgrass, thereby enabling genome sequencing, simplifying genetic map construction, and allowing determination of population structure with regard to polyploidy. Now that a diploid line is available, switchgrass varieties with desirable traits can be developed using established breeding techniques.

Quantifying net energy balances for switchgrass: An important step in developing the nation's bioenergy potential is determining the economics and net energy balance for perennial-grass feedstock production systems. Through large-scale field studies over a five year period, ARS scientists at Lincoln, NE, determined that switchgrass cultivation netted a positive energy balance averaging 60 GJ ha^{-1} y^{-1}, which translates into 540% more renewable energy produced than nonrenewable energy consumed. Switchgrass managed for high yield had equal or greater net energy than low input, restored prairies and can produce twice as much liquid fuel per acre.

Energy cane: Sugar cane is being considered as a dual-use crop for producing both sucrose sugar for human consumption and bioenergy (by converting the cellulosic bagasse). ARS scientists, in collaboration the Louisiana State University, released three varieties of high-fiber sugarcane (so-called "energy cane") that excel in total biomass yield. [this research was funded through NP301]

Screening Switchgrass Cultivars for Ethanol Production Efficiency: ARS tested the "convertability" to ethanol of over 100 different samples of switchgrass which varied widely in environmental growth conditions and genetic traits. The results show that there can be a wide spectrum of conversion yields from switchgrass and validate the need to develop switchgrass varieties and production practices specifically for use as a feedstock for ethanol biorefining.

Pyrolysis of Ligno-cellulosics: ARS scientists developed and tested a 3-inch pilot-scale, fluidized-bed, fast pyrolysis reactor for converting switchgrass, alfalfa stems and chicken litter into bio-oils. One of the largest poultry grower/processors in the U.S. is entering into a CRADA to use this reactor to produce bio-oil from chicken litter and to design a scale-up prototype for commercial demonstration