AGRICULTURAL RESEARCH SERVICE
2007 TETRAPARTITE MEETINGS
BIOENERGY RESEARCH AND DEVELOPMENT

ARS Bioenergy research: past accomplishments

The Agricultural Research Service (ARS) is the intramural research arm of the U.S. Department of Agriculture (USDA). Over the past several decades, ARS scientists have made many key contributions in the fields of biofuel research and development:

- Initiated switchgrass breeding, genetics, and management research and led efforts to develop switchgrass and other perennials for biofeedstock
- Identified genes regulating cell wall lignin and cellulose modification
- Determined that major plant cell wall genetic modification can adversely affect plant fitness
- Promoted corn bran (fiber) as a source of biomass for fermentation
- Discovered the first yeast that ferments xylose
- Developed improved microbial biocatalysts for biomass conversion
- Developed methods for enzymatic conversion of biofeedstocks
- Developed biomass pretreatments to facilitate enzymatic hydrolysis
- Assessed how biofeedstock harvest management strategies impact ethanol yield
- Developed rapid screening assay for predicting ethanol yield from biofeedstocks
- Produced and characterized pyrolysis from switchgrass in a fluidized bed reactor
- Developed strategies for plant cell modification in a "White Paper" requested by the U.S. Department of Energy

Present and future research

Current ARS bioenergy research is focused on three areas:

<u>Cellulosic feedstock development and production</u>: ARS scientists are developing the fundamental knowledge and basic science needed to identify and understand barriers to accessing and using biomass as a source of bioenergy, fuels, and biobased products.

The ARS Cell Wall Initiative (CWI) focuses on using genomics to understand and manipulate all the genes that control cell wall content and synthesis in order to develop biofuel crops with optimal ethanol conversion characteristics. ARS researchers have already cloned the Corngrass gene from mutant maize plants, which can be used to develop corn plants with multiple tillers and reduced lignin content; a maize gene that regulates leaf growth has also been cloned. In addition, CWI researchers are leading national and international efforts to develop a range of genomics and transformation tools for perennial grasses and establish a model grass system for bioenergy research. CWI goals include developing and modifying biofeedstock (including modification of the plant cell wall) to produce maximum crop yield and superior quality, and providing

technological support for the commercial production of cellulosic ethanol from agricultural crops.

ARS bioenergy crop breeding is focused on developing energy crop cultivars with good agronomic traits, high yield, optimum energy value, and minimal environmental impacts. Current research is being conducted on dedicated energy crops including alfalfa, energy cane, switchgrass, reed canarygrass, *Miscanthus*, bermudagrass, napiergrass, and others. These crops, which provide increased biomass yields, can be grown on marginal land not currently suitable and/or cultivated for food, feed, and/or fiber crops. Legume energy crops such as alfalfa can be grown in cropping systems with corn, which not only results in a high-yield bioenergy crop, but also supplies free nitrogen fertilizer to corn, thus increasing corn yields as well.

Cellulosic feedstock conversion: ARS researchers are also investigating methods for facilitating the efficient and economic utilization of plant materials for cellulosic ethanol conversion. Future research in conversion technology will focus on:

- Biological conversion, and developing more efficient processes to disassemble plant materials to pentose and hexose sugars that are easily fermented
- Development of microorganisms, enzymes, and biochemical pathways for the efficient conversion of biomass to biofuels/energy and products
- Thermochemical conversion, including the development of energy efficient, reliable, and economical small scale gasification and pyrolysis processes that are easy to operate for on-farm use.

An immediate research objective for the biochemical conversion of cellulosic material to biofuel is developing cost-effective techniques for accessing and fermenting the glucose stored in plant materials. Near-term efforts will concentrate on conducting the basic science needed for developing more effective enzymes for cellulosic and hemicellulosic hydrolysis in conjunction with novel pretreatement strategies. In addition, the application of new biocatalyst development, in parallel with new conversion technologies, will generate industrially relevant strains capable of fermenting all of the sugars present in these feedstocks.

Feedstock farming production systems: ARS scientists are conducting ongoing research to design agricultural systems that produce optimal crop yields with minimal inputs in a wide range of climate and weather conditions that prevail throughout the United States. The success of the biofuel industry, particularly the conversion of cellulosic ethanol, will depend in large part on developing reliable supplies of cellulosic biomass within 25-50 miles of processing facilities. In addition, the development of on-farm energy sources will accelerate the development of a biofeedstock production system that requires minimal energy inputs. Future research in the area of feedstock farming production systems will focus on:

- Developing technology that improves the energy efficiency of agricultural systems and facilitates the sustainable exploitation of energy from agriculture
- Feedstock production, including the development of management practices for the sustainable and economical production of large quantities of quality material

- Feedstock logistics, including economical, on-farm methods for harvesting, handling, storing, and adding value to biomass feedstock.
- Developing and validating waste water treatment technologies and agricultural production systems that optimize contaminant loads in waste water with energy crop production requirements and the natural buffering capacity of soils

Challenges in future research

Two significant challenges currently hinder the development of adequate biofuel supplies to supplement existing fossil fuel sources: process and price. Breaking down the tough plant lignin and hemicellulose to access the five- and six-carbon sugars needed for the efficient conversion to biofuels, bioenergy, and bio-products remains a major challenge/opportunity.

Proof-of-concept research has been completed on cellulose conversion processes, but to date no large-scale commercial biorefinery has validated the utilization of these processes for the conversion of large amounts of cellulose. With existing conversion methods, biofeedstock requires separate steps for pretreatment, conversion, and fermentation, all of which add time, money, and energy inputs. In order to generate even greater levels of public and private funding for continued research into cellulosic production and conversion, the costs for obtaining ethanol via cellulosic conversion must meet or beat the production/conversion costs of corn grain ethanol. Consolidated bioprocessing (CBP) could offer an alternative cellulosic ethanol processing sequence through the development of a microorganism capable of facilitating enzymatic conversion, hydrolysis, and fermentation of pretreated biomass in a single reactor, and theoretically provide a substantial savings in cellulosic ethanol conversion costs. Researchers believe the development of such a CBP microorganism is feasible.

Expected outcomes

Current ethanol supplies are derived from corn grain, but the cultivation of corn requires significant agricultural inputs, and concern is already building about whether using increasing quantities of corn grain for ethanol will reduce the corn available for food and feed. These factors increase the odds that public and private support for research into cellulosic ethanol will continue.

First-generation commercial cellulosic ethanol operations will probably be built adjoining existing corn ethanol and/or paper mill facilities, thus lowering construction and processing costs, although integration levels will be limited because the conversion processes differ. For example, corn bran from corn ethanol plants could serve as a low-cost available biofeedstock, and biorefineries co-located with paper mills could also use cellulose-based byproducts generated by paper products manufacturing as biofeedstock.

Although crops suitable for biodiesel production are also being developed, biodiesel has a much stronger presence in Europe. However, both Europe and the United States share a commitment to developing biofuels to supplement fossil fuels, and there is ample room for scientific cooperation and collaboration on biodiesel and cellulosic biofuels/bioproducts research and development. For example, new, durable high-turnover and high-selectivity catalysts for converting syngas to biofuels/energy would make thermochemical conversion much more attractive for a wide range of feedstocks and biofuels.

Areas of potential cooperation among international researchers

- Genetic studies of potential biofuel crops, including oilseeds and grasses

- Research and development of enzymes and microbial organisms to facilitate cellulosic pretreatment, hydrolysis, saccharification, and fermentation.

- The development of value-added bioproducts for consumers and industry that displace existing petroleum based products and create industry and consumer markets for the new products