ARS Research on Bioenergy and Co-Products

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The US Department of Agriculture (USDA) recently published[1] a strategic energy-science plan under the auspices of the Research Education and Economics mission (REE). Figure 1 summarizes the vision and goals.

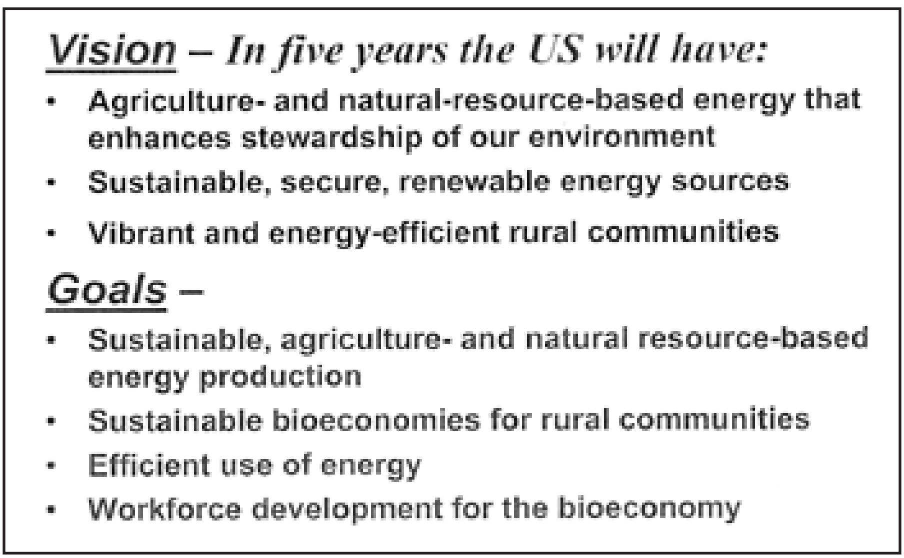

Figure 1. USDA REE strategic energy-science plan.

[1]http://www.ree.usda.gov/news/bead/USDA_REE_strat_plan.pdf.

Sustainability will remain front and center in our work, with special emphasis on rural economies. Also, within the Agriculture Research Service, we have retooled bioenergy—one of twenty-two programs—for the next 5-year cycle. Before it was focused mostly on biorefining, whereas now it has been expanded to include feedstock development and feedstock production (Fig. 2).

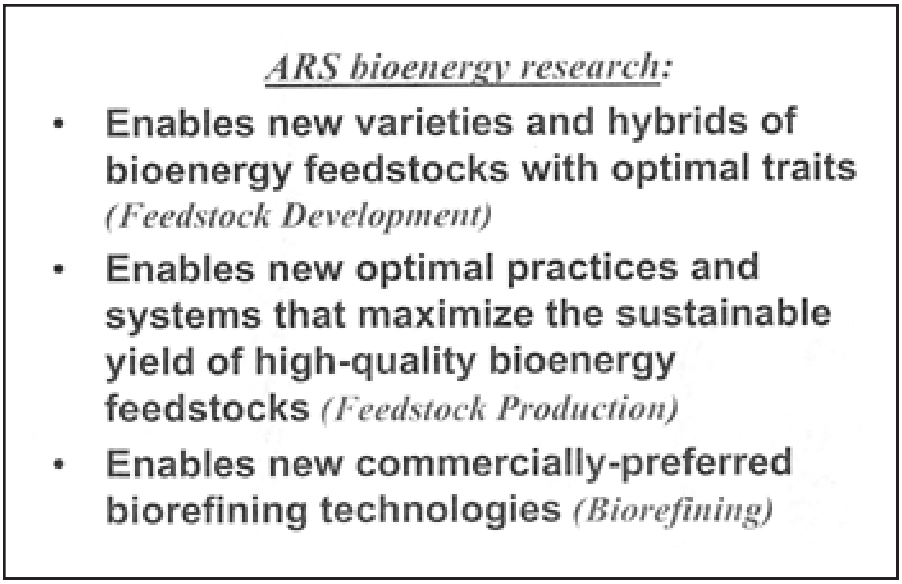

Figure 2. ARS bioenergy research: strategic vision.

Federal Coordination

Much effort is expended in coordinating the efforts of the USDA/ARS and other parts of the federal government. The Biomass R&D Initiative Board will soon publish a federal-wide biofuels action plan. Other interagency working groups include a temporary one examining feedstock availability, and others are examining feedstock-production sustainability and biomass conversion. We have a science-exchange program with the Office of Science and their bioenergy research centers. Inside the USDA there is the Energy Council at the undersecretary level and the Biobased Products and Bioenergy Coordination Council, which is composed of people at my level doing more hands-on coordination of programs and efforts.

Bioenergy Research

ARS research on bioenergy involves multiple programs. The most important is the Bioenergy Program, in addition to which a number of the other twenty-two programs include research that contributes to bioenergy. Again, there are three major components in the new Bioenergy Program: feedstock development, feedstock production and biorefining.

I share leadership roles with Kay Simmons, who leads our team on feedstock development, and Jeff Steiner on feedstock production. I head up biorefining as well as the overall integration. Feedstock development has two major components. One is looking at the molecular and genetic bases for plant traits that are important for bioenergy production, understanding the basics, and then using that knowledge, among other tools, for breeding new, superior germplasm.

For feedstock production we are focusing on three major areas. First is sustainable practices for feedstock production. We are also focused on developing decision tools that would help producers as well as biorefinery operators understand what kinds of feedstocks—and how much—might be produced sustainably on a particular farm in a particular region and the economic implications for the producer and the region. And we are working on on-farm utilization of byproducts from the char to gasification ash to distillers dry grains (DDGs).

With respect to biorefining, a number of efforts are ongoing, including biochemical conversion, not only of starches and sugars but also cellulosics and wastes. Emphasis on cellulosics constitutes the major part of the program. We are also investing in thermochemical approaches—gasification as well as pyrolysis—at the farm-scale or near it.

We have a strong biodiesel-research program, working closely with industry, particularly on fuel quality, which is still an issue. We also have a unit that helps us all in the biorefining area with process economics, to help us focus with respect to conversion technologies.

Co-Products

Co-products are a strong component of our program and require grantees to declare, up front, technology-transfer plans and partnerships. Much of the ARS work on co-products from biorefining occurs at four regional research centers:

- The Western Regional Research Center, Albany, CA
- The National Center for Utilization Research, Peoria, IL
- The Eastern Regional Research Center, Wyndmoor, PA
- The Southern Regional Research Center, New Orleans, LA

They were designed as utilization centers for developing new products and processes for utilization of excess materials from agriculture.

History of Achievement

These examples of contributions from the USDA give a sense of the activities in the regional research centers:

- 1943—Linoleic and linolenic acids were found to retard the process for producing synthetic rubber from butadiene and styrene; the problem was solved by partial hydrogenation.
- 1944—Epoxidation was discovered, enabling production of flexible vinyl
- 1950—Economical methods were developed for producing dextran, from cane or beet sugar, as an alternative to blood plasma for use in the Korean War.

- 1950—Xanthan gum was developed as an edible food ingredient fermented from glucose by a microorganism.
- 1976—SuperSlurper was invented—a combination of starch and a synthetic chemical that absorbs hundreds of times its own weight in water—initiating the superabsorbent industry.
- 1994—Fantesk was invented—an inseparable mixture of starch and oil that has numerous food and non-food applications.
- 2000—Nutrim was patented—a soluble oat fiber nutraceutical obtained from thermo-mechanical processing.

From Biodiesel Synthesis

The major co-product in biodiesel production is glycerol for which we have been working on a number of possible uses. One of them is the production of polyhydroxyalkanoates (PHAs), including polyhydroxybutyrate. We can actually obtain better yields of these materials if we make them from the biodiesel-based glycerol, probably because of small amounts of nutrients that would otherwise be considered as contaminants, but in this case are beneficial.

Other co-products from glycerol include microbial sophorolipids, which have several potential applications:

- Surfactants, detergents
- Cosmeceuticals (skin regeneration)
- Source of novel oleochemicals
- Source of bioactive disaccharides (inducer of fungal cellulases)
- Excellent antimicrobial agent

From Ethanol Synthesis

Co-products from ethanol refineries that we've been working on include corn fiber, which is typically a low-value material. We have developed corn-fiber oil, which has nutraceutical properties; it has been patented and licensed to Monsanto and a large corn refinery, among others. We have patented corn-fiber gum, which National Starch is using as an emulsifier and thickener agent in paints.

Some 95% of the oil in the corn kernel is in the germ, which is obtained by hexane extraction. We have developed a highly efficient enzymic extraction process that eliminates the use of solvents.

Another co-product is thin stillage from which we can extract and produce the carotinoid astaxanthin, which is used in feed on salmon farms to impart the characteristic red color, circumventing the need for expensive fish meal. Also, enzymic hydrolysis of corn fiber and distillers' grains provides novel oligosaccharides for use as probiotics, *i.e.* non-digestible carbohydrates that stimulate growth of beneficial bacteria in the colon.

Another application for distillers' grains again is in aquaculture. We developed a relatively inexpensive feed that is now used broadly for tilapia production.

There is a misconception that there are no co-products from cellulosic biorefineries. One that we've developed is xylitol, the five-carbon polyol, that's used as a food sweetener. It has anticariogenic properties and is used also in dental products, chewing gum, soft drinks, ice cream, *etc*. The traditional production route for xylitol, by catalytic reduction of hemicellulose hydrolyzate under alkaline conditions, is low-yielding and expensive. We have developed two alternative processes using recombinant microorganisms. In one it is made from xylose, and in the other from L-arabinose.

Land-Grant Collaboration

A number of our scientists work closely with university collaborators. In collaboration with B.J. Singh at the University of Illinois we developed a new milling method for corn-starch refining, which is being commercialized. That work involved scientists at our Eastern Regional Research Center outside of Philadelphia. We encourage people to look for required expertise within the ARS system as a whole, rather than for who is closest. On the other hand, many of our laboratories are co-located in land-grant universities and our scientists not only collaborate scientifically with faculty but also participate on graduate-student committees and teach as adjunct faculty. We are proud of these ties with the university community and look forward to continuing them under a new Farm Bill and new administration.

In November, 2004, **robert fireovid** joined the national program staff of the USDA-ARS to help lead research programs in quality and utilization (*i.e.* bioproducts). Previously, he was at the Department of Commerce's National Institute of Standards and Technology where he spent 10 years as a program manager in the Advanced Technology Program (ATP). While at ATP, he led nationwide programs in high-risk/high-payback R&D within the chemical, materials, agricultural and industrial biotechnology industries and worked with companies such as Cargill-Dow, Genencor, Metabolix, Seminis, Cognis, Metabolix, Maxygen/Verdia, Maxygen/Codexis and CropTech. Currently, he is the ARS national program leader for bioenergy research.

Dr. Fireovid has been involved in research on bioenergy and biobased products since his PhD work on ethanol fermentation of cellulosic feedstocks over 30 years ago, including bioproducts research on penicillin fermentation and enzymatic production of 6-aminopenicillic acid (Wyeth Laboratories), the conversion of lactic acid to acrylics (Corn Products), and fermentation-derived food additives (Hercules). In addition to a PhD in chemical engineering, he has an MBA from Northwestern University. He served as a business manager at Black & Decker and GE Plastics.