Fueling a Hungry World

Developing Biofuel Feedstocks that Don't Cut into Food Supply

by Jeff Mulhollem

As the world confronts a reported food shortage and rising fuel prices—giving the public second thoughts about committing massive amounts of corn to ethanol production—scientists around the globe and at Penn State are scrambling to develop biofuel feedstocks that won't divert food crops to energy and drive food costs higher. Even if corn wasn't needed to feed the hungry masses—both directly and through animal agriculture—the environmental degradation stemming from corn production is troubling.

Corn is the single biggest crop grown in this country. In many U.S. corn-growing regions, farmers incur significant costs to purchase and apply large amounts of nitrogen fertilizer. However, only about half of the nitrogen fertilizer applied to corn is used by the crop, according to Penn State plant nutritionist Jonathan Lynch, and some of it leaches from the soil, contaminating streams and groundwater. Because fossil fuels are used to produce nitrogen fertilizer, such waste reduces the net energy gains from the crop.

"In the last few years, corn's ability to take up nitrogen has taken on greater importance because of increasing amounts of the crop being used to generate ethanol, which has contributed to rising corn prices," says Lynch, who is developing corn varieties with root architectures that are more efficient in taking up nitrogen.

Beyond corn, scientists are studying a smorgasbord of plants as potential biofuel feedstocks, notes Tom Richard, director of Penn State's Institutes of Energy and the Environment, but he doesn't see a silver bullet. "The answer to our energy challenge will have to be multifaceted," he explained. "In an effort to decrease greenhouse gas emissions, expand domestic energy production, and maintain economic growth, public and private investments are being used to pursue a wide variety of dedicated feedstock crops for biofuel production."

corn

soybean

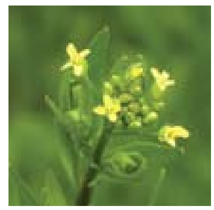
Unlike food crops grown for grain-based ethanol, the best candidates for biofuel feedstocks don't require high inputs of fertilizers and pesticides and don't have to be grown on prime agricultural land. Proposed "lignocellulosic-based" energy crops (woody plants and perennial grasses) typically sequester carbon as they improve soil quality, require relatively few economic or environmental inputs, and can be cultivated on marginal, lower-productivity land.

"Thus, a rapidly growing industry related to crop selection, cultivar improvement, and conversion technologies is emerging," says Richard. "In the coming decade, we expect the biofuels industry to expand beyond using corn to using lignocellulosic biomass to make ethanol and other liquid fuels."

Penn State is developing new perennial crops for the lignocellulosic biofuels industry by both conventional breeding methods and through the use of advanced technologies that overcome many of the problems associated with breeding undomesticated perennial plants, such as switchgrass. "Our goal is to increase the yield of biomass crops without increasing the input costs," says Richard. "Additionally, we are developing varieties that are better suited for processing to fermentable sugars."

Language in the new farm bill contains significant incentives for cellulosic biofuels, according to Richard, who believes "that is really good news for Pennsylvania." He explains that the state has hundreds of thousands of acres of abandoned farmland and revertible pastures available for growing perennial grasses, such as switchgrass, and fast-growing trees, such as hybrid poplar. Also, Richard points out, the state and much of the Northeast is covered by forestlands that have been undermanaged for decades, replete with small-diameter trees with the potential to be marketed as bioenergy feedstocks.

poplar



camelina

"But perhaps most significantly, we need new strategies for our most-productive agricultural lands to produce increasing amounts of food crops while also producing biofuels on the same acreage—planting bioenergy cover crops in the 'off season' between food crops," Richard says. "When the land is not used, farmers should be planting winter grasses to prevent runoff, and those cover crops can also serve as biofuel feedstocks. If we can get something green on the landscape year-round, and get some bioenergy value out of it, that will be a good thing."

Small-diameter trees in Pennsylvania forests could sustainably provide a significant bioenergy resource, according to agronomist Greg Roth.

The College of Agricultural Sciences is collaborating with Penn State's Colleges of Engineering and Earth and Mineral Sciences on a just-finished biofuels energy pilot plant in Fenske Laboratory on the University Park campus. Research on getting energy from various feedstocks will be accomplished there and at the Earth and Mineral Sciences Energy Institute's thermochemical pilot facilities. But Richard concedes that small-scale pilot plants are only the beginning.

switchgrass

jatropha

"More than a half dozen companies are spending about a half billion dollars in private capital nationally to build plants, leveraged by $400 million in federal government money," he says. "The earliest large-scale plants are probably not going to make a lot of money, but they will position the companies to build successful second-generation plants that should be very profitable."

While there remains much room to improve on biofuel technologies and feedstocks, Richard is convinced that the idea of a society largely powered by biofuels is not pie in the sky. "Penn State scientists are working on a range of research to improve the technologies," he says. "They are working on the front end—such as logistics, storage strategies, pretreatment with microbial systems, and enzymes to break down the plant fibers—and the downstream processes, such as fermentation, fuel separation, and concentration, and development of vehicles better suited to burn these new fuels."

Penn State's role also includes providing insight to public policymakers to help them ensure that businesses invest in the technologies that will make the best use of the resource base, according to agronomist Greg Roth. "I think within ten years we will see some pretty innovative technologies appear," he says.

Roth predicts small-diameter trees in Pennsylvania forests could sustainably provide a significant bioenergy resource—whether from direct combustion, gasification, pelletizing, or ethanol production. "Oilseeds, too, have great commercial potential," he says. "We have made biodiesel from soybeans and canola—canola produces about twice as much oil as soybeans. Last year, we grew about six acres of canola and made about 600 gallons of oil."

The college is currently studying sunflowers, which produce seeds that are 40 percent oil. By "double-cropping" sunflowers with wheat (planting sunflowers in early July after wheat is harvested), Pennsylvania growers could produce biofuel and food crops annually in the same fields. "Sunflowers, along with soybeans, canola, and camelina, are the best plants for producing oil that can be grown at this latitude," says Roth.

Researchers are continuing to experiment with biomass crops, such as switchgrass, and annual crops, such as sorghum. "This year we will grow a European crop called miscanthus, similar to ornamental grass," Roth says. "Miscanthus is promising because it grows taller and is higher yielding than switchgrass. It is too soon to say, but we think Pennsylvania can have a tremendous forest biomass crop and lots of land that could be cultivated with switchgrass or miscanthus."

As with every biofuel, key questions are being asked, Roth explains. What is the impact of growing the feedstock on the environment? What are the greenhouse gas emissions from burning the finished fuel? What is the price of the feedstock? What is the potential yield of the biofuel?

"Processing technologies are changing and will eventually move away from sugar- and starch-based biomass to woody, cellulosic sources," he says. "Current technology requires large supplies of a single material. But in Pennsylvania, we have diverse supplies of fuel stocks, so we need technologies that do not require homogeneous materials."

One source of woody biomass that holds great promise as a biofuel feedstock is fast-growing hybrid poplar, and Penn State molecular biologist John Carlson is studying the trees for their potential energy value. A few years ago, he served on a steering committee for the International Poplar Genome Consortium, which helped the U.S. Department of Energy chart a path for the groundbreaking genome sequencing of the poplar tree.

Trees in the *Populus* genus, such as cottonwoods, hybrid poplars, and aspens, are being used in a variety of ways ranging from paper production to carbon sequestration. Penn State biomass scientists are interested in developing those trees as a source for renewable, bio-based fuel products.

Jatropha is perhaps the most promising known biofuel feedstock, according to molecular biologist Mark Guiltinan, shown here with the plant in a campus greenhouse. Jatropha is being grown in more than a few tropical regions, such as India and Indonesia. Penn State researchers are developing higher-yielding, pest-resistant plants.

Crawford County Camelina Conversion

In most places in the east, they're still talking about the coming biofuels revolution. But in Crawford County, Pennsylvania—thanks largely to Penn State Cooperative Extension—farmers already are involved in it.

The local extension office has taken the lead in organizing a group of growers into a co-op that will produce a promising biofuel feedstock. "We have about 300 acres of the oilseed camelina planted on a dozen farms here," says Joel Hunter, extension educator based in Meadville. "This is a right-here, right-now thing. We have a huge new market for vegetable oil for biodiesel, and we will be selling the oil to the Lake Erie Biofuels plant just to the north in Erie."

The plant, which opened in the fall of 2007, has a capacity to make 45 million gallons of biodiesel a year from vegetable oils and other fat sources, according to Hunter. "They will buy all the oil we can give them," he says. "It's a huge operation, and plant officials would love to develop a local supplier. Right now they have to bring in oil from out of the region."


Lake Erie Biofuels Plant

Hunter notes that executives with Lake Erie Biofuels asked extension specialists if camelina could be grown in northwest Pennsylvania, and the answer was found in studies recently conducted by the University of Montana. "Once we were sure we could grow it, we were pretty aggressive because it looked like a real opportunity," he says. "We brought it up with growers at meetings last fall and winter and urged them to try it. There was so much interest, we actually turned people down."

Extension purchased 1,000 pounds of camelina seed for farmers to grow. "We went out on a limb to make this happen, but we knew that even if we didn't get grants to cover the cost, we were willing to invest that much to get the effort off to a running start because it is such a good idea," says Hunter. "In recent years, there has been increasing interest in developing agronomic systems with low requirements for fertilizer, pesticides, and energy and that provide better soil-erosion control than conventional systems. Camelina could play a key complimentary role in a no-till systems approach based on cover crops and rotations."

With a growing season of just 85 to 105 days, the climate in northwestern Pennsylvania limits farmers' ability to "double-crop" in most cases, Hunter notes. "We liked camelina because it fits into our crop rotation, and it can be no-till planted, planted early, and then followed by another crop. It seems to integrate well into our primarily dairy agriculture here."


Camelina

Camelina originated in the Mediterranean region. The annual plant attains heights of 1 to 3 feet and has branched stems that become woody at maturity. Leaves are arrow shaped, sharp pointed, and about 3 inches long with smooth edges. The plant produces prolific small, pale-yellow or greenish-yellow flowers with four petals. Seed pods are the size and shape of a small pea.

The camelina will be harvested with combines when it is mature, according to Hunter. The seeds are very small, amounting to about 400,000 seeds per pound, and they are 40 percent oil, compared to 20 percent with soybeans.

Extension is working with the owners of a crush plant in Union City to extract the oil while making arrangements with various partners on other details, such as transportation of the crop. "Handling seeds this small is really a challenge, but a key partner, Ernst Seeds in Meadville, has the expertise and equipment to handle it," Hunter says. "We want to make the program bigger in 2009, adding acres and growers. We want to convince more people to get involved, and in a few years extension will step away and let capitalism take over."

A few details still need to be worked out, but everything is looking good, Hunter says. One of those details is what to do with the remaining meal after the oil is pressed out of the camelina seeds. As with the camelina oil, the meal is high in omega-3 fatty acid, which means the nutritional value of the meal is high. That should make it attractive to farmers feeding livestock.

"The potential is there to do value-added ag products from the meal," says Hunter. "We are hoping we can feed it to poultry for production of high-omega-3 eggs. But at this point, we would settle for just feeding it to livestock. "

—Jeff Mulhollem

"The sequencing of the poplar genome is a bonanza for researchers seeking to understand how individual genes influence the growth of trees and their adaptation to the natural environment," Carlson explains. "We are trying to apply this knowledge to the breeding of fast-growing trees capable of producing wood, fiber, and energy on a smaller amount of land."

Populus trees have emerged as model organisms in forestry for the same reasons that *Populus* was chosen as the first tree genome to sequence: rapid growth rate, small genome size, and widespread use in plantation forests, Carlson explains. "Cottonwoods, hybrid poplars, and aspens could play a role in improving the environment, displacing imported oil, and creating domestic jobs," he says. "But first, scientists need to better understand the biology of *Populus*, for which the genome sequence provides the blueprint."

Siela Maximova, a horticultural research associate, selects young jatropha stock. The goal is to improve the plants and then multiply them with propagation, using molecular biology to speed the process.

Perhaps the most promising biofuel feedstock being studied by Penn State researchers can't be grown in Pennsylvania, or even in most of the United States—it's a tropical plant called jatropha that can grow in gravelly, sandy, and saline soils. Because jatropha is not edible and can grow in harsh climates, it can be planted in areas where it won't compete for resources needed to grow food.

When jatropha seeds are crushed, the resulting oil can be processed to produce a high-quality biodiesel that can be used in a standard diesel engine, while the "seed cake" (what is left after the oil is pressed from the seeds) can also be processed into fuel to be burned in electricity generators. The plant yields more than four times as much fuel per acre as soybean.

Despite its abundance and use in countries such as India and Indonesia, none of the jatropha species have been properly domesticated and, as a result, their oil productivity is variable, and the long-term impact of large-scale jatropha crops on soil quality and the environment is unknown. That's where Penn State scientists come in.

"Jatropha is not a secret—they are intensely working on it in China, India, the Netherlands, and at least two other labs in the United States that I know of," says molecular biologist Mark Guiltinan. "We are all doing the same things, but we are all probably doing them slightly differently—some putting plant material and what they learn into the public sector, others keeping it under wraps. But no matter what we do, the market will never be satiated because there is a tremendous need for biofuels."

Guiltinan, who is collaborating with plant geneticist Majid Foolad and researcher Siela Maximova, met with Ministry of Agriculture officials in Indonesia last year about establishing jatropha crops. "The project's goal is to initiate a comprehensive research program for the improvement of jatropha," he says. "We are taking existing varieties and—using molecular biology and breeding—creating better-yielding, pest-resistant plants. We want to make jatropha plants better, then multiply them with propagation. We are using molecular biology to speed up the process."

Guiltinan and Maximova are renowned for their work developing improved cocoa plants, and Foolad made a name for himself developing the Penn State tomato with enhanced traits for blight resistance and increased lycopene content. "Because of our experience with cocoa and tomatoes, it was really easy to design this study," Guiltinan says. "We are at the point in our careers where we know what we need to do. The thing is, jatropha has not been improved yet—they are just wild plants. We think in a relatively short time we can make really significant improvements."

Guiltinan predicts that vast plantations of jatropha will be established on marginal lands around the world in tropical regions. "This is going to be huge," he says. "Small villages are going to be built for workers, and they will need schools, wastewater-treatment facilities, power—everything. The idea is that the jatropha oil will be taken from collection points near the plantations by tankers and shipped to wherever it can be used."

Faculty referenced in this article are John Carlson, professor of molecular genetics and director of the Schatz Center for Tree Molecular Genetics; Mark Guiltinan, professor of plant molecular biology; Jonathan Lynch, professor of plant nutrition; Greg Roth, professor of agronomy and Penn State Cooperative Extension state program leader for renewable and alternative energy; and Tom Richard, associate professor of biological engineering and director of the Penn State Institutes of Energy and the Environment.