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LOUISIANA Agriculture

Assuring Our Future Through Scientific Research and Education

Expanding the biofuel industry

Sugarcane, sweet sorghum, switchgrass and more

LSU AgCenter
Research & Extension

Hydrogen and Biofuels

Svetlana Oard

Hydrogen is an appealing energy carrier because of its potential for using the most plentiful resources – water and sunlight – to power one of the most environmentally clean reactions, $2H_2O = 2H_2 + O_2$, in which two water molecules yield two hydrogen molecules and one oxygen molecule. The United States, the European Union and Japan have already embarked on establishing hydrogen fuel stations, and in parallel, car manufacturers have invested extensively in the development of hydrogen fuel cells to power cars.

Scientists recently discovered that green microalgae, or phytoplankton, can produce hydrogen. The development of microalgae-derived hydrogen could deliver the means for a solar-powered, carbon dioxide-sequestering (and therefore economical and intrinsically environmentally safe) biofuel. The warm and humid climate makes Louisiana one of the most suitable states for industrial-scale production of microalgae through inexpensive, pond-based systems. Algal ponds can be established on nonarable land otherwise unsuited for growing crops. This means more business opportunities for Louisiana. Moreover, there will be no competition between biofuel crops and food crops.

Many people believe that algae-based technologies will lead to new fast-growing biofuels and have a huge potential to boost Louisiana's economic development. The research to create microalgae for hydrogen production will require a united effort of scientists with expertise in advanced computer modeling, quantum chemistry, enzymology, genetics and biological engineering. The natural enzyme that produces hydrogen in microalgae is sensitive to the presence of oxygen. Scientists have to re-engineer the enzyme to make it oxygen-tolerant. This will radically improve the current capability of microalgae to produce hydrogen. Fortunately, the AgCenter has scientists willing to rise to the challenge. They are in the process of establishing collaboration with scientists from the National Renewable Energy Laboratory, a unit of the U.S. Department of Energy.

An economical process has to include three components: scalable and economical algae cultivation, improved microalgae capable of producing hydrogen in the presence of oxygen, and commercial use of hydrogen as a transportation fuel. LSU AgCenter scientists have designed and built a reactor for mass producing algae and have developed an aquaculture system utilizing a fuel cell to maintain oxygen levels.

To engineer microalgae with improved capability to produce hydrogen, the first step is to use advanced computational methods to investigate the effects of oxygen on the structure and dynamics of the hydrogen-producing enzyme hydrogenase. Knowledge gained from this process will help guide the design of improved, oxygen-resistant enzymes, which will be tested experimentally in a model organism. The next step is to develop a controlled production system that will produce the active hydrogenase under desirable conditions in microalgae. The production system will be used to introduce improved enzymes into microalgae to increase hydrogen production.

A successful research and development project will open doors for many new jobs in Louisiana and will have a broad national and international effect because of the worldwide importance of economical hydrogen production. Hydrogen can be converted into electricity, and manufacturers are developing automobiles that use hydrogen as a fuel. In addition, chemical companies use tons of hydrogen for hydrogenation reactions. Hundreds of millions of tons of ammonia fertilizer are produced annually using hydrogen and nitrogen. Most hydrogen currently comes from reforming natural gas and refining petroleum. Consequently, these large-scale hydrogen consumers are among the existing industries that can use this technology. Thus, invention of an economical process for producing hydrogen biofuels with microalgae will have a major, positive effect on several industries in Louisiana and beyond.

Svetlana Oard, Associate Professor, LSU AgCenter Biotechnology Laboratory, Baton Rouge, La.

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ON THE COVER: Photoillustration by John Wozniak

What's New?

MarketMaker will boost Louisiana agriculture, seafood industry

Louisiana's agriculture and seafood industries will have a new marketing tool in early 2010 when MarketMaker, a national Internet-driven service, is inaugurated in the state.

"Louisiana MarketMaker will serve as a central clearinghouse for any agricultural commodity in the state, including seafood products and specialty crops," said Paul Coreil, LSU AgCenter vice chancellor and director of the Louisiana Cooperative Extension Service.

"The service will help producers find a market anywhere in the country for their products," Coreil said. "This raises our agricultural marketing efforts to the next level. This will be a huge boost for our rural economy."

The service will be possible because of Community Development Block Grant funding from the Louisiana Recovery Authority (LRA), the Louisiana Department of Wildlife and Fisheries (LDWF) and the Louisiana Department of Agriculture and Forestry (LDAF), which have committed $125,000 in startup and operations funding to keep the program going for three years.

In addition, the program will be sustained after the initial three years with support from LDWF, LDAF and the Louisiana Farm Bureau Federation, Coreil said.

MarketMaker, which was developed and is managed and maintained at the University of Illinois, is already in place in 12 states and the District of the Columbia. The Southern states up and running include Mississippi, Georgia, Kentucky and South Carolina. Arkansas and Florida are gearing up to launch the program, like Louisiana.

MarketMaker is more than an Internet-based database. It also has the ability to analyze the market, taking advantage of other databases, including the Census. It will allow Louisiana producers to research customer demographics by location, ethnicity, household characteristics and income.

"Producers have the ability to search out and find the most likely markets for their products," Westra said.

Louisiana producers can sign up for the training at any LSU AgCenter office. The training on using Louisiana MarketMaker begins in the spring of 2010. ■ **Rick Bogren and Linda Foster Benedict**

LSU AgCenter gets $518,000 for blueberry Web site

The LSU AgCenter, along with a Mississippi agriculture agency and three other southern universities, has been awarded a $518,000 grant to develop an interactive, educational Web site about blueberries.

The site's purpose will be to teach people in the southeastern United States how to grow this commodity, which is increasingly popular, and to encourage consumers to eat more blueberries, which are a valuable source of many nutrients and fiber.

The "All About Blueberries" site will be part of eXtension.org, which is a national Web site aggregating information from 74 universities across the country.

The grant is from the U.S. Department of Agriculture (USDA) through its Specialty Crop Research Initiative. The LSU AgCenter's four partners in the project are the USDA's Agricultural Research Service in Poplarville, Miss.; Mississippi State University in Starkville; Auburn University in Auburn, Ala.; and North Carolina State University in Raleigh. ■ **Linda Foster Benedict**

West Carroll students use technology to improve safety

Three West Carroll Parish high school students learned enough sophisticated computer technology that they were able to create digital fire district maps, which will be used to improve local services in the parish.

"This started two years ago on a cold January morning when the students went to get 4-H training on GIS in Baton Rouge," said James Barnes, director of the LSU AgCenter's Delta Rural Development Center in Oak Grove. "It sparked an interest for this type of work."

GIS stands for Global Information System and is a type of computer technology that takes advantage of information from satellites.

Photo by Mary Ann Van Osdell

James Barnes, director of the LSU AgCenter's Delta Rural Development Center, left, and Forest High School students, left to right, Dustin Waits, Charles Dupree and Seth Strong.

Students Seth Strong, Dustin Waits and Charles Dupree from Forest High School were trained in GIS technology and collected data points for every fire hydrant in West Carroll Parish. Fire chiefs gave them feedback along the way.

"When the community wants something to happen in the delta, it happens. This will save property, time and, most importantly, lives," said Dwight Landreneau, LSU AgCenter associate vice chancellor.

The project was completed Sept. 11, and the maps in the forms of framed posters and compact discs have been presented to fire chiefs in eight districts.

"We can have a map of every district for our automatic aid agreement. Shared information is always a good thing," said Mike Berry, fire chief in Forest.

Waits said he had a good feeling about doing a project that can save lives, and Strong said he will add the project to his resume and plans to major in civil engineering in college.

The other LSU AgCenter agents helping with the GIS training were R.L. Frazier, Madison Parish; Dennis Burns, Tensas Parish; Myrl Sistrunk, West Carroll Parish; and Keith Morris, adjunct assistant professor in the Department of Biological & Agricultural Engineering. ■ **Mary Ann Van Osdell**

10 schools get started with Louisiana 4-H Seeds for Service

Students at Warren Easton High School in New Orleans along with 10 other schools around the state really know what it means to get down and dirty, thanks to a $25,000 grant secured by the LSU AgCenter's 4-H Youth Development office.

Pamela Marquis, LSU AgCenter 4-H agent in Orleans Parish, is working with the 19 students from Andrea Spreter's math and science classes to make the garden a success.

"This is a win-win situation for the school and for 4-H. The students gain practical experience working in the garden, and we get to bring 4-H programming into the school," Marquis said.

She said the school garden is bountiful with vegetables such as tomatoes, lettuce, peppers, cabbage, collard greens, onions, squash, beets and cauliflower.

"The goal of this project is to grow kids by igniting a passion for learning, success and service through a unique gardening education," said Janet Fox, associate professor in 4-H Youth Development.

Warren Easton High School, in collaboration with LSU AgCenter, recently received a $1,000 grant from the Louisiana Serve Commission for the Louisiana 4-H Seeds for Service School Garden program.

The other schools involved in the program include: Sacred Heart Elementary in Moreauville; Beauregard Alternative School, DeRidder; Ingersoll Elementary School, Shreveport; Ralph Wilson Elementary School, Lake Charles; Central/SSAAC, Ville Platte; Dorseyville Elementary, Dorseyville; Carencro Middle School, Carencro; Belle Chase Academy, Belle Chase; Start Elementary and Middle School, Start; and Cypress Cove Elementary, Cypress Cove.

For information on how to start a vegetable garden at your school, contact your local LSU AgCenter extension office or visit the Web site at www.lsuagcenter.com. ■ **Johnny Morgan**

Photo by Johnny Morgan

Students at Warren Easton High School in New Orleans pull weeds, spray for insects and water plants in their vegetable garden.

Valverde's photo selected for virology journal

The Journal of General Virology, a prestigious international journal of virus research published by the Society for General Microbiology in the United Kingdom, has selected a photo from Rodrigo Valverde, professor in the Department of Plant Pathology & Crop Physiology, for its October 2009 cover. The photo accompanies his manuscript, "A novel plant virus with unique properties infecting Japanese holly fern," co-authored with Sead Sabanadzovic from Mississippi State University. Valverde and his colleague researched the biological and molecular properties and full genome sequence of a new emerging virus species in the United States. ■ **Linda Foster Benedict**

TGRx gets first $30 million contract

TransGenRx (TGRx) – a biotechnology company started by licensing technology from the LSU AgCenter – has landed its first contract worth $30 million. TGRx will produce human growth hormones for an Argentinean pharmaceutical company, called Cassara, over the next 12 to 18 months. Cassara will distribute the hormone in medicines primarily in Central and South America.

TGRx, which was established in 2002, produces specialized proteins. The initial technology used involved changing genes in chickens so they would produce specialized proteins in their eggs. Although the company is still perfecting this technique, TGRx has switched its focus to cell culture for the creation of these proteins, according to Richard Cooper, company executive vice president and an LSU AgCenter researcher.

"TGRx is one of only a handful of biotechnology companies in Louisiana. These companies face many challenges in getting started and being able to sustain themselves. The accomplishments of TGRx are good for the state," said David Boethel, LSU AgCenter vice chancellor for research. "We're pleased with the role our research was able to play in bringing this technology forward."

Under the licensing agreement, the AgCenter receives 5 percent of TGRx sales and has a 15 percent stake in the company. This first contract should generate $1.5 million in royalties for the AgCenter, Boethel said.

TGRx is located in the Louisiana Emerging Technology Center, which is a technology incubator facility for start-up companies on the LSU AgCenter campus. The facility was initially funded through the Louisiana Economic Development Department. ■ **Linda Foster Benedict**

Photo by Mary Ann Van Osdell

Opportunities for Louisiana in the Expanding Biofuel Industry

Michael E. Salassi

LSU AgCenter researchers are investigating use of switchgrass at a source of bioenergy. This plot is at the Hill Farm Research Station in Homer. Read more on page 22.

The biofuel industry in the United States has expanded tremendously over the past decade. Consumption of biofuels has increased faster than any other energy source in recent years. The rapid expansion of this relatively new industry has occurred as the result of several factors, the most important of which has been this country's growing dependence on foreign oil, which primarily is converted into transportation fuels for use by U.S. consumers and businesses.

In 2008, the U.S. Department of Energy reported that U.S. consumption of crude oil and petroleum products was 19.4 million barrels per day. Domestic production of crude oil (from Alaska and the lower 48 states) declined 39 percent since 1973 and was only 6.7 million barrels per day last year. As a result, the United States imported 12.7 million barrels per day of crude oil in 2008 to meet our energy needs. These imports accounted for 65 percent of our total petroleum consumption. By comparison, petroleum imports in 1973 were 6.3 million barrels per day, accounting for only 36 percent of total petroleum consumption.

Production of biofuels from renewable feedstocks in this country provides a means for decreasing our dependence on foreign oil. With its diverse agricultural and forestry production sectors, Louisiana has tremendous potential to develop its own biofuel industry.

Challenges currently facing the biofuel industry include the food-versus-fuel debate and the broad diversity of potential crops for use as biofuel feedstocks. Biofuel research and extension efforts in the LSU AgCenter are under way in the areas of feedstock development and biofuel production. LSU AgCenter scientists are identifying opportunities for Louisiana in this new and expanding industry.

What are biofuels?

Several terms are commonly used in the news media when referring to the expanding bioenergy industry,

Michael E. Salassi, Fairbanks Endowed Professor, Department of Agricultural Economics & Agribusiness, LSU AgCenter, Baton Rouge, La.

Photo by Bruce Schultz

Sweet sorghum at a research plot at the Rice Research Station in Crowley.

including renewable energy, biomass and biofuel. It may seem these various terms all refer to or mean the same thing. Actually, each of these terms is distinctly different, although directly related to each other.

Renewable energy refers to those sources of energy that are naturally replenishing but limited in quantity at any one time. Examples of renewable energy include energy generated from hydropower, geothermal sources, biomass, and solar and wind power, as well as ocean thermal, wave and tidal actions. In 2008, renewable energy accounted for 7.5 percent of total U.S. energy consumption.

Biomass is one type of renewable energy source and generally refers to any organic, nonfossil material of biological origin. Currently, the United States has three primary sources of biomass renewable energy – wood, waste and biofuels. Last year, biomass energy sources represented 53.2 percent of renewable energy consumption and 3.9 percent of total U.S. energy consumption. Wood is the most common type of biomass energy source and has a long history of providing energy for heating and cooking as well as producing steam for electric generation. Waste as a source of biomass energy is primarily composed of municipal solid waste burned for energy or biogas captured from landfills. Biofuels, the third major biomass energy source, consist primarily of ethanol and biodiesel. Produced from biomass sources and used for transportation fuels, biofuels are the fastest-growing source of energy in the country today.

Biofuel industry grows

In 1980, the United States produced 175 million gallons of ethanol for use as a transportation fuel. By 1995, the annual production level had risen to 1.4 billion gallons. However, over the next several years as the price of gasoline rose and the cost of corn, the primary feedstock used in producing ethanol, remained relatively cheap, U.S. domestic production of ethanol skyrocketed. Construction of ethanol plants expanded tremendously, primarily in the Midwest to minimize corn feedstock transportation costs. U.S. ethanol production was 2.1 billion gallons in 2002 and increased to 9 billion gallons in 2008. The Renewable Fuels Association reports that the total number of ethanol plants in the United States expanded from 50 in 1999 to 170 in 2008. Production capacity over the same period increased from 1.7 billion gallons to 10.5 billion gallons per year with another 2.0 billion gallons of capacity currently under construction. The use of ethanol as a transportation fuel in blends with gasoline has surpassed domestic production in recent years. Most ethanol imported to make up this shortfall has come from countries such as Brazil, El Salvador, Jamaica and Costa Rica.

Although much smaller in scale than ethanol, biodiesel production in the United States in recent years has expanded just as dramatically. Biodiesel can be made from a variety of feedstocks – including soybean oil, canola oil, other vegetable oils, animal fats and recycled cooking grease – and serves as a direct substitute for diesel made from petroleum. In 2000, only 2 million gallons of biodiesel were produced in the United States. By 2008, this annual production value increased to 683 million gallons. With current biodiesel fuel use only about half of domestic production, the United States has become a net exporter of biodiesel, with the majority of these exports bound for the European Union.

Photo by Bruce Schultz

Jerry Whatley, extension agent in Calcasieu Parish, tells farmers about sweet sorghum at a field day.

Industry faces challenges

Despite its tremendous recent growth, the biofuel industry in the United States faces several major challenges. One of these concerns the so-called food-versus-fuel debate. The argument by some interest groups is that corn should be used for food, a more pressing basic need, rather than fuel. Furthermore, some have argued that the use of corn as a feedstock in ethanol production was one of the major causes of the recent rise in commodity and food prices.

For the 2008-09 fiscal year, the U.S. Department of Agriculture estimated 4 million bushels of corn – 29 percent of the total U.S. corn supply – were used for ethanol production, with the remainder used for food, feed and exports. Earlier this year, the Congressional Budget Office released a study that reported that the rise in the price of corn resulting from expanded production of ethanol contributed only 0.5 to 0.8 percentage points of the 5.1 percent increase in food prices from April 2007 to April 2008, as measured by the consumer price index. Other factors, such as higher energy costs, were reported to have a greater effect on food prices than the use of corn as an ethanol feedstock.

A more critical challenge facing the biofuel industry is related to the process used to make biofuels. Until now, the primary feedstock to produce ethanol in this country is corn, and the production process involves conventional, long-established fermentation technology. However, when evaluating biofuel production from a technical efficiency standpoint, the production of ethanol per acre of feedstock using conventional fermentation procedures is much less efficient in the use of those feedstocks and land resources compared with more advanced biofuel production technologies.

Much of the focus of current research is in the area of advanced biofuels using cellulosic, syngas and algae production technologies. Cellulosic ethanol production, as the name suggests, uses cellulose in various plant materials as the primary feedstock. Syngas, a synthetic gas used as an energy source, contains varying amounts of carbon monoxide and hydrogen, which can be produced from biomass feedstock sources. Oil produced by algae is being converted into biodiesel, and algae's carbohydrate content can be converted into other types of biofuels, including ethanol and butanol. Although the use of corn as an ethanol feedstock and soybean oil as a biodiesel feedstock is expected to continue to grow over the next several years, the future direction of the biofuel industry lies with the development and commercialization of these more advanced production processes.

Related to the development of cellulosic ethanol production is the corresponding challenge of identifying the optimal feedstock for use with this technology. Unlike corn ethanol production, which has few feedstock substitutes, cellulosic ethanol can be made from a wide variety of biomass sources. In theory, the cellulose in any plant material can be broken down to produce ethanol. Potential cellulosic ethanol feedstock sources include trees, agricultural crops and perennial grasses. The array and availability of these potential feedstocks vary tremendously across the country.

Louisiana has probably one of the greatest arrays of diverse feedstock production potential for cellulosic ethanol and advanced biofuel production in the country. High-fiber "energy" sugarcane, switchgrass and miscanthus are just a few of the potential feedstock crops being evaluated. The challenge is to identify those feedstocks for which a particular state or region has a comparative advantage. Production costs, harvest costs and transportation costs of these potential feedstocks are all critical factors in this challenge.

AgCenter research, extension help lead

With its diverse array of agricultural and forestry production enterprises, as well as its extensive petroleum and natural gas infrastructure, Louisiana has tremendous potential to develop an economically viable and sustainable biofuel industry. Such an industry has the capability to provide the state's existing agricultural and forestry sectors with new opportunities to produce additional commodities and products that would enhance their long-term economic viability.

The LSU AgCenter has a broad array of ongoing research projects and extension activities that have the overall goal of identifying opportunities for Louisiana in the new and expanding biofuel industry. Articles included in this special focus issue of *Louisiana Agriculture* provide a summary of the wide-ranging areas of investigation the LSU AgCenter is pursuing in biofuel feedstock evaluation and production technologies.

Current research and extension activities across units within the LSU

Photo by Sonny Viator

Sweet sorghum at a research plot at the Iberia Research Station in Jeanerette. Read more on page 16.

AgCenter cover a broad range of bioenergy feedstock development and biofuel conversion technologies.

- Scientists at the Audubon Sugar Institute are evaluating cellulosic ethanol production utilizing energy cane as a feedstock as well as utilizing biochemical and thermochemical processes to produce a variety of “second generation” biofuels.
- Researchers in the School of Plant, Environmental & Soil Sciences are investigating a variety of alternative biodiesel feedstock crops including winter cover crops as well as alternative tree species.
- Hill Farm Research Station scientists are conducting research on switchgrass grown in an agroforestry system, while Iberia Research Station scientists are leading a multi-unit research project on sweet sorghum.
- Faculty in the Department of Biological & Agricultural Engineering Department are conducting research in the areas of microwave technology in biodiesel production, gasification of biomass feedstocks and ethanol production from algae.
- Scientists at the LSU AgCenter Biotechnology Laboratory are conducting advanced research in the use of microalgae for hydrogen production.
- Projects in the School of Renewable Natural Resources involve investigating hydrothermal processing of biomass, while conversion of wood and other biomass into liquid and gaseous products is being analyzed at the Calhoun Research Station.
- Scientists at the Callegari Environmental Center are evaluating the quality characteristics of biodiesel production.
- Researchers in the Department of Agricultural Economics & Agribusiness are evaluating the economic feasibility of producing of alternative biomass feedstock crops as well as alternative biofuel production methods. ■

Photo by John Wozniak

Kenneth Gravois has led a sugarcane breeding project to develop new varieties of “energy” cane high in biomass and suitable as a source for bioenergy.

Developing a Cellulosic Ethanol Industry in Louisiana

Tyler B. Mark, Michael E. Salassi and Michael A. Deliberto

The Energy Independence and Security Act of 2007 is a comprehensive energy-policy law passed by Congress with the primary purpose of increasing energy efficiency and the availability of renewable energy in the United States. A key provision of the act was the Renewable Fuels Standard, which established a modified standard of renewable fuel use in U.S. transportation fuels of 9 billion gallons in 2008 rising to 36 billion gallons in 2022. Of the 36 billion-gallon renewable fuel goal for 2022, 16 billion gallons are required to be "cellulosic ethanol."

Ethanol currently produced in the United States is made primarily from corn using conventional fermentation technology. Cellulosic ethanol is a biofuel that can be produced from a wide variety of feedstock plant materials – called biomass – including trees, agricultural crops and grasses. To reach these mandated levels of biofuel production, each U.S. region or state will need to produce the feedstock crop for which it has a comparative advantage.

Louisiana's subtropical climate makes it an ideal location for the production of biomass. Louisiana has an average yearly temperature of 66 degrees, average precipitation of 64 inches per year and growing days ranging from 230 to 290 in the southern part of the state. Under these conditions, the state can produce a wide variety of energy feedstock crops, such as energy cane, switchgrass, miscanthus, sweet sorghum, woody crops, etc.

The infancy of the cellulosic ethanol industry, however, poses many unanswered questions. LSU AgCenter agricultural economists are evaluating the costs of producing energy cane, the competitiveness of cellulosic ethanol from energy cane given today's technology and conversion processes, and the pricing of this crop by processors purchasing the feedstock from local producers.

In 2007, the Louisiana Agricultural Experiment Station, in conjunction with the American Sugar Cane League and the U.S. Department of Agriculture (USDA), released three energy cane or high-fiber cane varieties. These new energy cane varieties are to be feedstock for cellulosic-ethanol production facilities. The yield potential, in tons of biomass per acre, is much greater for these varieties compared with traditional sugarcane varieties grown for sugar production.

Production-cost budgets for energy cane were developed based on existing sugarcane production practices and were adjusted for projected yields per harvested acre as well as stubble crop duration. Current sugarcane production in Louisiana typically consists of four annual harvests of the planted crop before replanting is necessary. The first crop harvested after planting is referred to as the plant cane crop. The following three harvests are referred to as the first-stubble, second-stubble and third-stubble crops. Higher yield potential for energy cane varieties would be expected to result in more years of harvest for those varieties compared to existing sugarcane varieties. Harvest of energy cane as a cellulosic ethanol feedstock crop could be expected to extend through a fourth-, fifth- or sixth-stubble crop.

Estimated costs of producing energy cane at alternative harvest yields are shown in Figure 1. These cost estimates are based on harvest through a fourth-stubble crop (five years of harvest) and represent average estimated production costs at the whole-farm level for a farm in a normal crop rotation pattern, that is, with equal areas of the farm acreage in fallow/plant, plant-cane, first-stubble, second-stubble, third-stubble and fourth-stubble crops. Three production cost estimates are shown. Grower cost includes variable and fixed farm production costs associated with producing energy cane. The other two cost estimates include additional land rent and hauling. Land rent in this analysis is on a one-sixth share, and hauling is included at $3.50 per ton.

Grower cost plus rent and hauling would represent an estimate of what a cellulosic ethanol production facility would have to pay to acquire the energy cane as a feedstock. Hauling cost would vary with the distance between the farm and the production facility. This feedstock would then have to be dried to be in a form usable in ethanol production. Production cost estimates show that one of the primary factors in the economic feasibility of cellulosic ethanol is in producing a crop that has a high biomass yield per acre. The greater the biomass yield per acre, the lower the feedstock cost per gallon of ethanol produced.

Tyler B. Mark, Graduate Student, Michael E. Salassi, Fairbanks Endowed Professor, and Michael A. Deliberto, Research Associate, Department of Agricultural Economics and Agribusiness, LSU AgCenter, Baton Rouge, La.

Figure 1. Estimated costs of producing energy cane at alternative harvest yields.

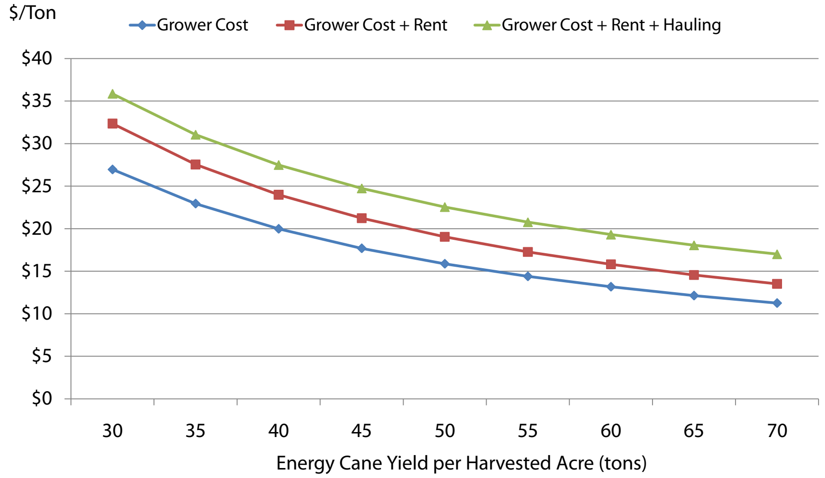
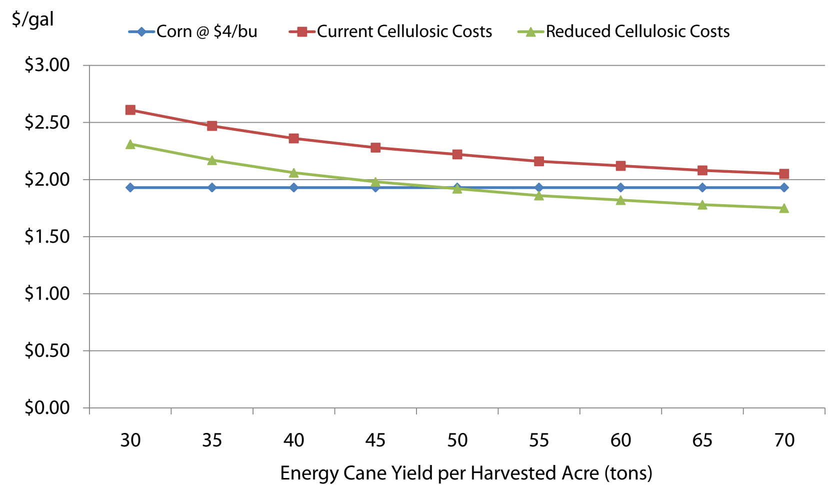


Figure 2. An ethanol-production cost comparison for corn ethanol and cellulosic ethanol using energy cane as a feedstock.



Currently, no commercial production of cellulosic ethanol is taking place in the United States on a large scale. Several pilot plants are in operation, and a number of companies have announced plans to begin construction of cellulosic-ethanol production facilities using conversion technologies each company has been developing. In 2007, the USDA published some preliminary cost estimates of cellulosic ethanol conversion. Using this information in conjunction with the producer breakeven costs for energy cane production in Louisiana, a comparison can be drawn on how competitive the cellulosic ethanol industry is with traditional corn ethanol. Figure 2 shows an ethanol-production cost comparison for corn ethanol and cellulosic ethanol using energy cane as a feedstock. With a corn price of $4 per bushel, ethanol production costs for corn using conventional fermentation technology would be approximately $1.93 per gallon. Current estimates of cellulosic ethanol production costs indicate it would cost about $2.61 per gallon using energy cane at an average yield of 30 tons per acre. As harvested yields increase, ethanol production costs would decrease to an estimated $2.05 per gallon cost with energy cane yields of 70 tons per acre.

In addition to identifying the best feedstock crop for ethanol production in a given area, researchers are looking for ways to reduce cellulosic-ethanol production costs, primarily those associated with enzymes used. Figure 2 illustrates the effect of reduced cellulosic production costs on the economic feasibility of ethanol produced from energy cane compared with corn. In this example, enzyme costs are reduced by 10 cents per gallon of ethanol produced, and other cellulosic production costs are reduced by 20 cents per gallon. As research makes the cellulosic ethanol production process more efficient, enzyme costs and other production costs are expected to decrease, thereby making cellulosic ethanol from feedstocks such as energy cane more cost competitive with corn-based ethanol.

Identifying pricing mechanisms for biomass is pivotal for the development of the cellulosic-ethanol industry's supply chain. The infancy of the industry has left many agribusinesses and producers wondering how different feedstocks might be priced. Because biomass crops do not have a well-established market as corn and other traditional agricultural commodities have, considerable research is under way to determine the best way to price biomass as a marketable commodity.

In addition, because biomass would be purchased for fuel production, there is some discussion that the price paid to the grower should be correlated more with fuel prices. Numerous pricing strategies could be employed. Three possibilities include:

- Variable biomass price linked to the price of corn, ethanol or crude oil.
- Biomass price that would cover a fixed percentage of production costs plus a variable rate dependent upon biomass yields.
- Variable rate linked to crude oil price but with upper and lower limits on the price that a producer would receive.

The ultimate objective of any biomass-pricing mechanism would be to allow for the interaction of supply and demand to affect market price while at the same time ensure the price paid to growers would be sufficient to assure a steady and dependable supply of feedstock to the ethanol production facility.

Although cellulosic ethanol is being produced from a wide variety of feedstocks at the laboratory and pilot-plant scale across the country, many challenges must be overcome for commercial-size production facilities to become economically feasible. With its diverse agricultural and forestry production sectors and its favorable climate and growing conditions, Louisiana has tremendous opportunities to be a major player in cellulosic ethanol production. The LSU AgCenter is conducting research in a wide variety of areas focusing on identifying the best feedstock crops and most efficient production technology. Development of a cellulosic ethanol industry in Louisiana would complement existing agricultural and forestry production and enhance the economic viability of those industry sectors of the state. ■

Lignocellulose
A Source for Fuels and Chemicals

Giovanna M. Aita and Deepti Salvi

Biorefinery technology is a term coined in the 1990s to describe the fabrication of fuels, solvents, chemicals and plastics from renewable materials. By 2020, the United States is aiming to have at least 25 percent of organic-carbon-based industrial chemicals and 10 percent of liquid fuels from a bio-based industry. This challenge will require renewable resources – such as lignocellulosics, algae and municipal waste – to be produced at lower cost, in higher quantities and with properties suitable for efficient conversion.

A recent study conducted by the U.S. Department of Energy suggests that 1.3 billion tons of biomass are available in the United States each year to produce 130 billion gallons of liquid fuels, including ethanol, mixed alcohols, biodiesel, "green" gasoline and "green" diesel. The study also concluded that sufficient biomass is available to supply the raw materials now required for the production of industrial chemicals such as resins, polyesters, emulsifiers, "green" solvents and fuel additives.

Lignocellulosic biomass includes any plant material produced by photosynthesis. Potential sources of lignocellulose include agricultural residues such as corn stalks and wheat and rice straw, agricultural byproducts such as corn fiber, rice hulls and sugarcane bagasse, and energy crops such as switchgrass, sweet sorghum, high-fiber sugarcane and miscanthus grass. Lignocellulosic biomass as a source for biofuels and chemicals does not disrupt the food, fiber and feed chains and needs no major changes in energy requirements and agricultural practices. It can be sufficiently abundant to provide a major resource for making commodity-based fuels and chemicals (Figure 1).

Lignocellulose is made of three major components – cellulose, hemicellulose and lignin. Lignin is a highly complex material that gives plants strength and protection from the environment. Cellulose and hemicellulose are sugar polymers or chains of multiple sugars wrapped in a sheet of lignin. Table 1 shows the chemical composition of some lignocellulosic materials.

The ability to make fuels and other value-added products from lignocellulose relies on the separation and breakdown of lignin and sugar polymers into each of their components. In nature, lignocellulosic biomass is degraded over the years by natural forces and by microbes. In a biorefinery, however,

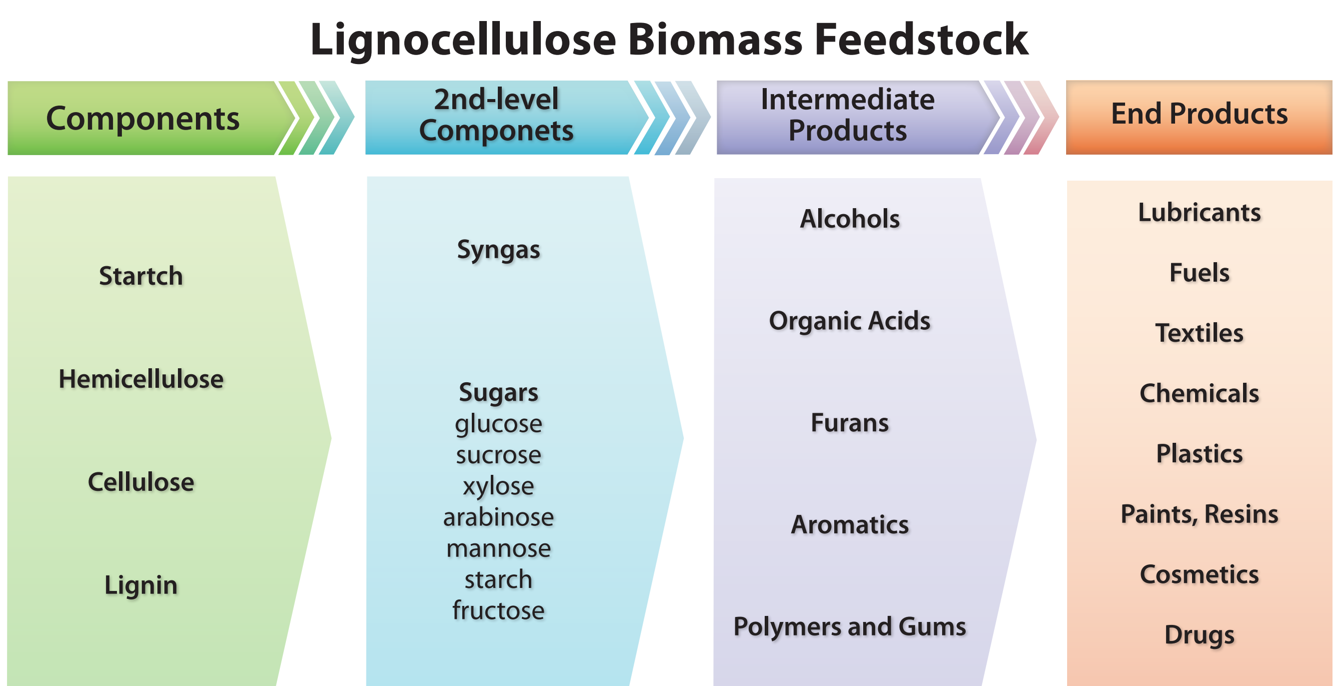


Figure 1. Flow chart of lignocellulose-derived fuels and chemicals.

breakdown of feedstocks must occur in a matter of hours or days. A number of technologies have been developed for improving the breakdown of lignocellulosic biomass. Available technologies include:

- Physical – mechanical sheering, freeze/thaw cycles, radiation.
- Thermochemical – acid catalyzed; base catalyzed; noncatalyzed using high-temperature and near-supercritical water, steam explosion, pyrolisis or gasification.
- Biological processes with microbes or enzymes.

The LSU AgCenter's Audubon Sugar Institute is working on producing fuels and value-added materials from renewable sources. In south Louisiana, raw sugar mills operate only three months of the year. The long-term research goal is to use the sugar mill year-round for producing not only sucrose, molasses and bagasse but also alternative products, without interfering with food-grade sugar production. Ethanol production from sugarcane bagasse, sorghum and energy cane has been an area of extensive research at Audubon. Audubon's technology uses dilute ammonia at high temperature and pressure to separate and break down the main components of lignocellulose. Ammonia-based pretreatments with or without heat and/or pressure break the links between lignin and sugar polymers, resulting in pore formation and swelling of biomass and enhancing further chemical and/or biological degradation (Figure 2).

Once the biomass has been treated with ammonia, the lignin, cellulose and hemicellulose product streams are generated. Cellulose and hemicellulose are further broken down by the addition of enzymes to glucose and xylose. Glucose is fermented to ethanol by the addition of a nonpathogenic and non-genetically modified yeast (Figure 3). Xylose is being studied for the production of compounds other than ethanol. Audubon's technology can yield 55 gallons of ethanol per dry ton of biomass from cellulose only. The target set by the U.S. government is 100-110 gallons per dry ton of biomass from both cellulose and hemicellulose.

Synthesis of nontoxic and biodegradable polyesters from sugarcane is another promising area of research being conducted at Audubon. Investigation is under way to isolate precursors from molasses and lignin found in pre-treatment wastes associated with the production of ethanol from ammonia-treated grasses – bagasse, sorghum and energy cane. The goal is to use these synthesized polymers as the basis for direct regeneration of tissue.

Deconstruction of lignocellulose followed by chemical or fermentation processes is expected to be a near-term and the most practical pathway to fuels and chemicals. Nevertheless, its success is highly dependent on overcoming biomass recalcitrance, detoxifying waste streams and developing new processes that can be applied commercially at low costs. ■

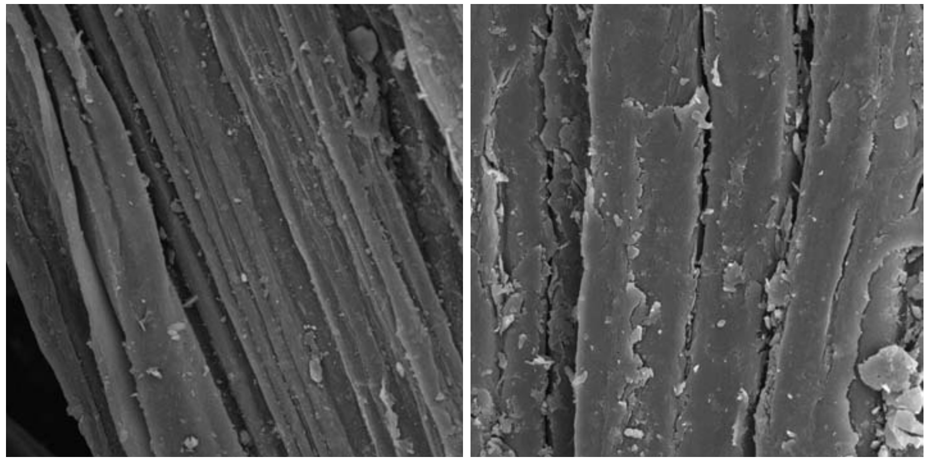


Figure 2. Scanning electron microscopy images of sugarcane bagasse before (left) and after (right) treatment with technology developed by the Audubon Sugar Institute.

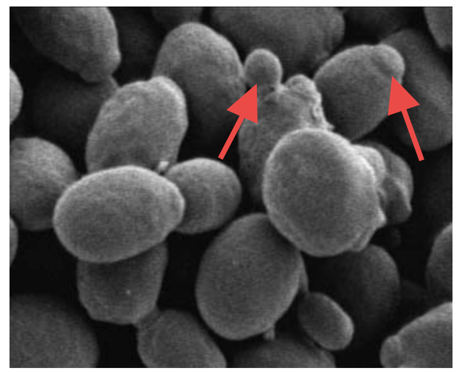


Figure 3. Cells budding on yeast.

Giovanna Aita, Assistant Professor, and Deepti Salvi, Postdoctoral Researcher, Audubon Sugar Institute, LSU AgCenter, St. Gabriel, La.

Table 1. Chemical composition of various lignocellulosic materials

Biomass	Cellulose	Hemicellulose	Lignin	Other*
		percent dry biomass		
Corn stover	36.4	21.4	17.2	25.0
Wheat straw	38.2	24.7	23.2	13.9
Rice straw	34.2	24.5	23.0	18.3
Miscanthus	31.0	24.4	17.6	27.0
Poplar sawdust	49.9	20.4	18.1	11.6
Sugarcane bagasse	40.2	21.5	24.2	14.1
Sorghum	44.5	27.7	22	5.8

*Protein, ash, acetyl, uronic acids, nonstructural sugars

Photo by John Wozniak

Producing Biofuels

Donal F. Day

Biofuels generally are defined as fuels produced from recently derived organic matter versus fossil fuels, which are derived from ancient organic matter. In either case, solar energy is the original energy source. Concerns about increasing levels of atmospheric carbon dioxide released from burning fossilized carbon, mixed with the desire to secure national energy supplies, have driven research on alternative fuels.

References to biofuels mean plant-derived oils, alcohols or burnable fibers. The desired form of fuel, either solid or liquid, and the technical difficulty in converting a specific feedstock into a fuel control the production. The value of a biofuel is fixed essentially by the wholesale cost of the fossil fuel it replaces, whether diesel or gasoline, coal or natural gas.

Successful biofuels have to meet the same performance characteristics as fossil fuels. Will they deliver the same performance as the fuel they replace for the same cost? And they must be usable in the existing infrastructure. A problem facing biofuel production is that the energy density of the feedstock – the available energy per unit of mass – is small compared with fossil fuels. This means that large volumes of feedstock must be used to obtain the same amount of fuel energy as from a smaller volume of crude oil or coal.

Biofuel usage varies across the world. Byproducts concentrated at industrial

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processing sites, such as bark and sawdust in saw mills, are the largest commercially used biomass sources. For example, bagasse, the fiber remaining after juice extraction in sugarcane processing, provides the energy for processing cane sugar at the sugar mill, and surplus bagasse can be used to supply electricity for local grids. In developing countries, biomass, particularly fuel wood and charcoal, is mainly used in open-combustion devices for cooking and, to a lesser extent, space heating.

Available liquid biofuels are usually biodiesel and ethanol, and solid biofuels are wood and biomass pellets. Biodiesel production requires an oil crop, which traditionally is soy or canola. The oil is cracked to free up the fatty acids, which are then transesterified with an alcohol. These fatty alcohols are burned as biodiesel.

Because the demand for this fuel is high and the traditionally available feedstock supplies are limited, interest is growing to develop technologies for producing bio-oil from algae. Selected strains of algae can contain 50 percent oil by weight, compared with wild algae, which contain around 10 percent oil. Large areas of land are required for open-water algal farms. Algae also can be grown in bioreactors, but getting sunlight into a closed tank is a problem. A readily available carbon dioxide source also is required, and the algae must be separated from large volumes of water prior to oil extraction.

The United States is the world's largest ethanol producer at 9 billion gallons per year, primarily from corn. This is about six percent of the United States' gasoline consumption. The ethanol production process uses a traditional technology, where starch is converted to sugars through use of enzymes and is then fermented into ethanol by yeast. The ethanol is captured by distillation.

Bioethanol production from corn underwent a rapid expansion during the past few years based on a rapid run-up in oil prices and favorable government support. A fall in oil prices halted this expansion and in some cases led to closing production facilities. Increased production from these corn-fed plants will require higher fuel prices and expanded sources of feedstock – for example, higher-yielding corn varieties – to be profitable again.

The large volume of gasoline used in this country requires an enormous feedstock source to produce enough biofuel to affect the nation's fuel supply. The largest available source is lignocellulose – biomass – which is estimated at 2.7 billion recoverable tons per year. This resource exists in diverse forms from grass to wood.

Considerable research has gone into defining methods of converting lignocellulose to useable liquid fuels. Alcohol from lignocellulosics can be produced by two basic processes –biochemical or thermochemical.

The biochemical approach requires technology for making the component sugars of biomass available for hydrolysis, converting the polymeric sugars into simple sugars and then fermenting them into ethanol. Biochemical processing depends on effective, low-cost methods for pretreating or reducing the complexity of the sugar polymers from the biomass and then technology for hydrolyzing these polymers to fermentable sugars. This approach potentially makes available a range of products derived from the lignin and minor sugar components of the biomass. It produces less alcohol per ton than thermochemical production and generates larger amounts of waste, which must be remediated.

The thermochemical approach involves burning the biomass in an oxygen-poor environment to produce a mixture of carbon monoxide and hydrogen. This synthesis gas can then be reformulated into alcohols. The thermochemical route is relatively feedstock-independent – it doesn't matter what is burned – but the feed must be homogeneous and clean and have low moisture content. Agricultural material does not normally meet these criteria, so much effort must be put into feedstock preparation. This process has the advantage of producing about 1.6 times the amount of alcohol per ton of feedstock as that produced using the biochemical method. There is, however, less chance for producing higher-value products to enhance the profitability of the process. The biochemical process has more flexibility in terms of potential products but is also technically more challenging.

Cellulosic ethanol is considered to be a first-generation biofuel. Second-generation fuels are those which are in development but are not as close to commercialization. They also are produced either thermochemically or biochemically. Agriculture underlies the country's push to biofuels (bio-ethanol, biobutanol, bio-oil), yet agricultural products are normally available only in a fixed window in time. Conversely, feedstock-independent flexibility in operation is a key to financial viability of any biorefinery.

The LSU AgCenter has a comprehensive research program designed to overcome technical hurdles blocking biofuel production in Louisiana. Projects range from finding multiple feedstocks suitable for year-round delivery and developing the tools for producers and processors to valuing these crops, developing the processing technologies for biofuels and finding supplemental, high-value byproducts from the process streams to improve the profitability of biorefineries.

The Audubon Sugar Institute conducts laboratory and pilot-scale research on potential alternative fuels ranging from producing ethanol from sugars and biomass at raw sugar mills and using starch-based products to produce butanol to systems for on-demand hydrogen production from water. The technology closest to commercialization after biodiesel is the production of ethanol from sweet sorghum, sugarcane bagasse and energy cane using resources at existing sugar mills.

Alkaline pre-treatment/hydrolysis options for lignocellulosic feedstocks have been successfully used at the Audubon Sugar Institute to reliably convert and ferment the cellulose in bagasse at a 30 percent solids loading with an 85-90 percent conversion rate to ethanol. This process has been extended from bagasse to sweet sorghum and energy cane.

Ethanol as a fuel has a distribution problem because its corrosiveness prevents it from being shipped in pipelines. Butanol, which also can be produced by fermentation of sugars, has higher fuel value and is noncorrosive. Audubon is looking to improve traditional butanol fermentation technology by increasing yields and productivity using traditional, sugar-containing feedstocks.

Biofuel production will not solve all our fuel problems, but in Louisiana, it is possible to produce sufficient biofuels to replace much of the gasoline used in this state. First-generation production facilities are being designed and built. Biofuels are in our future as a supplement to, but not a replacement for, fossil fuels. ■


Photo by Bruce Schultz

Sweet
for

The federal mandate for energy security through the development of sustainable biofuels has revived interest in sweet sorghum as a renewable energy crop. Sweet sorghum's advantages as a biofuel crop are that it contains large amounts of sugar for fermentation to ethanol and fiber for cellulosic conversion. Also, it has the attributes necessary to grow on all types of soil, even in relatively droughty conditions and on marginal land.

The LSU AgCenter has a long history of evaluating sweet sorghum varieties for the production of syrup, sugar and ethanol. The sugarcane industry through the American Sugar Cane League provided a grant to evaluate management practices, to identify geographic areas and soil types within the state best suited for production and to conduct economic analyses of different production scenarios. Specific objectives were to:

- Evaluate variety performance.
- Establish optimum nitrogen fertilizer rates.
- Assess the influence of plant density on yield.
- Determine the feasibility of growing a second (ratoon) crop from a single spring planting.

Plots were harvested at all sites at the hard dough stage of seed development, and stalk samples were taken to the Sugar Research Station in St. Gabriel, La., for assessment. Juice was extracted with a three-roller mill and then filtered before determining the percentage of soluble sugars. Sugar content was based on 90 percent juice purity. Resulting information is from only one growing season,

H.P. "Sonny" Viator is the lead scientist in a study of the feasibility of growing sweet sorghum as a biofuel crop in Louisiana. This plot is at the Iberia Research Station in Jeanerette, La.

Sorghum
biofuel production in Louisiana

H.P. "Sonny" Viator, Montgomery "Wink" Alison, Kenneth Gravois, Kun Jun Han, Dustin Harrell, Allen Hogan, W. "Buddy" Pittman, Michael Salassi and Jerry Whatley

and interpretations and recommendations made from some of the data are not conclusive.

Researchers are confident, however, that a sufficient number of production environments were sampled in 2008 to make a valid comparison of variety performance. Four varieties – M81E, Topper, Theis and Dale – were grown at the Hill Farm Research Station in Homer, Rice Research Station in Crowley and Southeast Research Station in Franklinton, and all but Dale were grown at the Iberia Research Station in Jeanerette. Both production and fertilizer management were not consistent across the four locations. Applied nitrogen fertilizer ranged from 60 pounds per acre plus previously applied manure to 120 pounds per acre, and plant density ranged from approximately 30,000 to more than 40,000 plants per acre.

In spite of these differences, the variety M81E surfaced as the highest-yielding variety under all growing conditions. Averaged over the test sites at Hill Farm, the Rice Station and Southeast Station, M81E produced more than 2,000 pounds more fermentable sugar per acre than the other varieties. At the Iberia station, it yielded equivalent to Topper. Theis showed problems with seedling emergence at several sites, which may have been a reflection of poor seed quality. Topper and Dale produced similar average yields between those of M81E and Theis. M81E also produced the highest yields on fields planted near Lacassine and Lake Charles to demonstrate sweet sorghum production practices to potential growers and processors.

Information gleaned from the other studies conducted during 2008 is considered preliminary and requires additional research before the data can be used. Certain observations, however, can be made. Ratoon yield at the Rice Station was about half of that of the first crop. Ratoon crops require fewer inputs than primary crops and may be economical at times when fall-planted crops like sugarcane do not immediately follow sweet sorghum in a rotation.

Pinpointing the fertilizer nitrogen requirements to optimize sorghum yield is a difficult and lengthy process because it relies on evaluating the response to applied rates across multiple locations and soil types rather than on tools that predict crop needs. The 2008 tests revealed that fermentable sugar yield tended to optimize at intermediate application rates in keeping with previous findings. High fermentable sugar yields achieved with high plant densities are encouraging and with further investigation may lead to a production system not currently practiced.

Production of sweet sorghum as a biofuel feedstock in Louisiana could be easily incorporated into an existing sugarcane production system. Sugarcane farmers could use the same harvest and transportation equipment. Sweet sorghum could be planted on sugarcane rows in the spring following the plowing out of the previous sugarcane stubble crop and preparation of the seed bed in a manner similar for sugarcane production.

Variable production costs of establishing a sweet sorghum crop are estimated to be approximately $193 per acre. This cost includes plowing out the previous sugarcane stubble and planting sweet sorghum and includes specific expenses for seed, fertilizer, herbicides, fuel and labor. At maturity, the sweet sorghum could be harvested with a single-row sugarcane combine harvester along with tractor/wagon units for transporting harvested sweet sorghum stalks from field to trucks for delivery to a processing facility. Estimated variable harvest costs are $145 per acre, using a diesel fuel price of $2.20 per gallon.

Sweet sorghum also could be produced on narrower rows, similar to corn or soybeans. Crop establishment costs would be somewhat lower for this scenario because fewer trips over the field would be required to prepare the seedbed for planting. The economic feasibility of this type of sweet sorghum production system would require the identification of a practical and cost-effective harvesting system.

Best management practices designed to protect soil and water resources have yet to be developed for sweet sorghum under Louisiana conditions. Because sweet sorghum uses water efficiently and requires relatively low nitrogen fertilizer rates, it should be considered to be a conservation-friendly crop. Moreover, growing sweet sorghum during the sugarcane fallow period is a best management practice that provides soil protection at a time the soil is vulnerable to erosion.

Sweet sorghum appears to be a promising biofuel crop, but the production knowledge base needed for commercialization does not compare favorably to staple crops like sugarcane, rice and cotton. The tools necessary to optimize production, such as weed control chemicals and fertilization practices, have not been completely identified at this point. Nevertheless, interest in producing ethanol from sweet sorghum is growing, with commercial production and processing rapidly becoming a reality in the state. ■

H.P. "Sonny" Viator, Professor and Coordinator, Iberia Research Station, Jeanerette; Montgomery "Wink" Alison, Coordinator, Macon Ridge Research Station, Winnsboro; Kenneth Gravois, Professor and Coordinator, Sugar Research Station, St. Gabriel; Kun Jun Han, Assistant Professor, Southeast Research Station, Franklinton; Dustin Harrell, Assistant Professor, Rice Research Station, Crowley; Allen Hogan, Agent, Jefferson Davis Parish, Jennings; W. "Buddy" Pitman, Professor, Hill Farm Research Station, Homer; Michael E. Salassi, Fairbanks Endowed Professor, Department Of Agricultural Economics & Agribusiness, LSU AgCenter, Baton Rouge; Jerry Whatley, Agent, Calcasieu Parish, Lake Charles, La.

Basics of **Biodiesel** Production

William A. Carney Jr.

More than 800 people across the state have learned to make biodiesel from used vegetable oil at LSU AgCenter workshops in 2008 and 2009. Participants have included farmers, owners of small businesses and individuals who want to save money and help the environment. They learn what equipment to buy and the chemistry involved. The workshops are held at the LSU AgCenter's W.A. Callegari Environmental Center.

William A. Carney Jr. with a freshly brewed sample of biodiesel.

You can make your own fuel to run in diesel engines for a fraction of what regular petroleum diesel costs. In fact, most people making biodiesel are making it for about $1 a gallon.

Biodiesel is most commonly made by chemically altering animal fats or vegetable oil through the use of a catalyst and an alcohol. The chemical reaction that occurs through this process breaks down the oil molecules and replaces the glycerin portion of the molecule with an alcohol molecule. To be successful at making fuel, the oil must be free from water and grit.

To make a batch of biodiesel, you heat the oil (triglycerides) to a designated temperature (130 degrees F to help with the chemical reaction) and then add a mixture of a catalyst (sodium hydroxide or potassium hydroxide) and an alcohol (methanol). The oil-catalyst-alcohol mixture is then agitated for two hours and allowed to settle, which can take 16-24 hours.

If the process is successful, the chemical reaction between the oil, alcohol and catalyst will have broken down the oil into several layers. The top layer will be biodiesel, chemically called an ester. The next layer may contain soap, and the bottom layer will be glycerin.

Once the layering has occurred, the glycerin and soap are drained off. The biodiesel is then washed with a water mist, a bubble wash or both. The washing removes any additional soap, alcohol or impurities.

After it's been washed, the biodiesel is then dried to remove the water. Commonly, it is then filtered through fuel filters and made ready to use in any diesel engine.

Making biodiesel typically takes a couple of days to a week from start to finish. Most people making biodiesel make anywhere between 20 to 100 gallons at a time in a batch process.

Equipment

Biodiesel can be made in anything from a 2-liter pop bottle to an elaborate processor complete with separate tanks for processing, washing, mixing, settling and filtering. Obtaining equipment is relatively easy. Most people get started by making small batches with minimal equipment and then gradually move up to making larger batches using processors built specifically for making biodiesel. Many home "brewers" either buy a variety of premade processors designed for biodiesel or make their own processors, either from kits or from plans found on the Internet. Professionally built processors can cost as little as $1,000 and as much as $15,000.

Using biodiesel

Biodiesel can easily be used in any diesel engine. Once processed, washed and dried, biodiesel can be poured into any diesel fuel tank. Biodiesel can also be mixed with petroleum diesel in any ratio. It easily mixes with petro-diesel and is most often sold commercially blended with petro-diesel. B20 fuel is common and consists of 20 percent biodiesel and 80 percent petro-diesel.

Within minutes of biodiesel being added to the fuel tank – and especially when used in high blend ratios of 50-100 percent – a noticeable difference begins. Most people report a reduction in engine noise, a smoothing of the engine and a noticeable change in the smell of the exhaust.

Research has compared biodiesel to petro-diesel across a wide range of

Photo by Mark Claesgens

. . .reduced emissions are reason enough to use this alternative fuel. Biodiesel is good for the environment.

parameters. One of the most significant differences is a drastic reduction in tailpipe emissions from biodiesel. Other significant reductions from use of biodiesel include hydrocarbons, carbon dioxide and particulate matter. For many, these reduced emissions are reason enough to use this alternative fuel. Biodiesel is good for the environment.

Besides better emissions, research has indicated an increase in engine longevity, a decrease in engine maintenance and a better-performing engine. Because biodiesel has solvent properties by nature, it acts as a cleaning agent on the fuel system in diesel engines. This means that it cleans things up the more it's used. Because of these solvent properties, some people have noted that fuel lines in older diesel engines (pre-1993) may degrade because the biodiesel breaks them down. Particularly susceptible are fuel lines made from natural rubber. Most of the susceptible fuel lines can be replaced easily with inexpensive biodiesel-compatible fuel lines.

Diesel engines made after 1993 and sold in the United States typically won't have this problem because the fuel lines are already biodiesel-compatible. This is because a reduction in sulfur in diesel fuel in 1993 in the United States caused manufacturers to change to non-rubber fuel lines.

Home brewers use biodiesel in varying blends, but most commonly it's used in blends from 20 percent (B20) to 50 percent (B50). When the weather drops below 50 degrees, it's recommended to blend biodiesel with petro-diesel, although a gelling effect does not occur much in Louisiana's warmer climate.

Another thing most people do when getting started is to change their fuel filters before using biodiesel and then change them again a few thousand miles later. This is to prevent the filters from plugging because of biodiesel's solvent properties. As it's used, biodiesel may knock residue from the walls of older fuel tanks and fuel lines that has built up from the use of petro-diesel. Replacing the fuel filters is just a precaution to ensure the engines keep on running.

The LSU AgCenter's W.A. Callegari Environmental Center is playing a vital role in meeting future domestic energy needs, such as for biodiesel. It produces alternative, renewable fuels as part of its waste-recycling and waste-minimization program. The center produces biodiesel from used vegetable oil from LSU campus food service operations for use in heavy equipment and transportation vehicles.

As part of the AgCenter's bioenergy research program, the Callegari Center plays an active role in developing alternative fuels. The center features a biodiesel plant that's used in conjunction with established laboratory procedures to characterize biodiesel and evaluate quality control procedures. Along with traditional food crops such as corn, soybean, sugarcane, sorghum and sunflowers, scientists are evaluating nonfood crops such as rapeseed, Chinese tallow and palm oil as feedstocks for biofuels. ■

William A. Carney Jr., Associate Professor and Head, W.A. Callegari Environmental Center, LSU AgCenter, Baton Rouge, La.

Precautions in biodiesel production

- Biodiesel production includes dealing with caustic chemicals, an alcohol called methanol, fair amounts of heat and the transferring of flammable fluids from one container to another. You need to have a fire extinguisher handy that is capable of putting out an oil-based fire.
- Biodiesel should always be made using proper safety equipment in a well-ventilated area away from children and pets.
- Using homemade biodiesel in a diesel engine may void a manufacturer's warranty. Read your warranty.
- Biodiesel is considered a fuel, so if it's used in a vehicle for on-road use, it may be subject to taxes. Check with state and federal taxing agencies if you have a question.
- Biodiesel itself, when properly made, is actually quite safe. It's less toxic than table salt and degrades faster than sugar. It has a higher flash point (the temperature at which it ignites) than regular petro-diesel, and if it's spilled, it isn't considered toxic.

Quality Control Aspects of Biodiesel

Ensuring Engine Safety

Javed Iqbal and Shelly L. Martin

Photos by Javed Iqbal

Figure 1. A: Incompletely reacted products settle to the bottom after dissolving biodiesel in methanol; B: Water and sediments settled to the bottom indicate poor washing and drying; C: Biodiesel meeting ASTM, D6751 specifications.

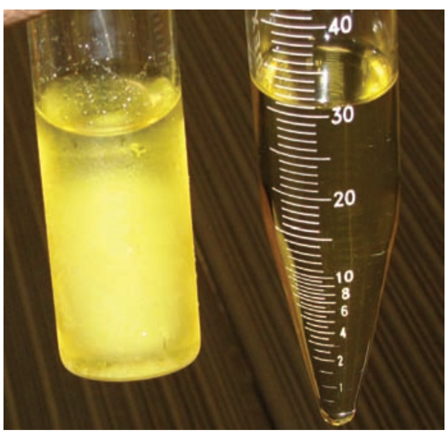


Figure 3. At left is biodiesel gelled at 26 degrees F; at right is biodiesel at room temperature 72 degrees F.

Making biodiesel fuel from vegetable oil or animal fat is a simple process. Rudolph Diesel used raw vegetable oil when he invented the first diesel engine in Augsburg, Germany, in 1893. Our modern engines, however, cannot digest the viscous oil used then. To avoid viscosity-related problems, used vegetable oils must undergo a chemical reaction called transesterification to be converted into biodiesel. In this process, oil molecules called triglycerides react with alcohols in the presence of a base catalyst such as lye. The product of the reaction is biodiesel, chemically named as mono-alkyl esters. Glycerin is a byproduct of the reaction. Theoretically, 100 gallons of oil or fat would react with 20 gallons of alcohol (usually methanol) in the presence of a catalyst (sodium or potassium hydroxide) to yield 100 gallons of biodiesel and approximately 22 gallons of glycerin.

Although no modification is needed to a diesel engine to use biodiesel, there is concern about the effects. Since 1993, manufacturers make diesel engines using materials compatible with biodiesel. Diesel engines made before 1993, however, may have natural rubber seals and fuel lines susceptible to slow degradation with biodiesel. Replacing such parts with current synthetic fuel lines is recommended to solve this problem. Rubber lines in new vehicles are mostly resistant. The switch to low-sulphur diesel fuel in the early 1990s caused wear and failure of injection pumps, and the manufacturers switched to resistant components, which are also resistant to biodiesel.

Poor quality biodiesel can cause short- and long-term engine and equipment problems. The American Society for Testing and Materials (ASTM) has, therefore, developed specifications for biodiesel fuel to ensure a certain quality of biodiesel for your vehicles. Poor

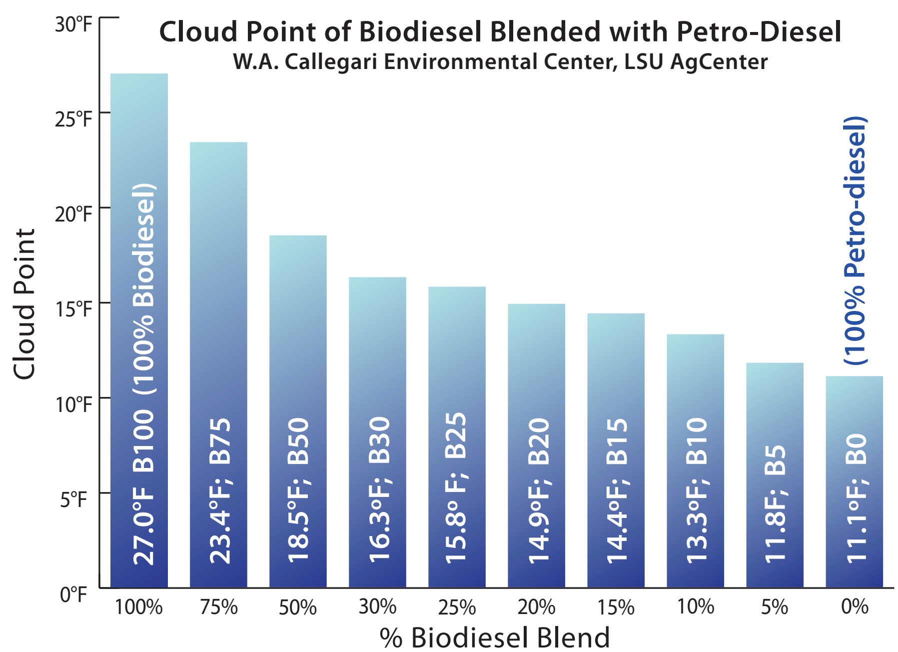


Figure 2. Effect of petro-diesel on the cloud point of biodiesel.

Javed Iqbal, Laboratory Manager, and Shelly L. Martin, Extension Associate, W.A. Callegari Environmental Center, LSU AgCenter, Baton Rouge, La.

quality biodiesel cannot leave the engine without problems. Though the effect will probably not be immediately noticeable, corrosion and damage can accumulate until the engine fails.

To avoid problems using biodiesel, it is advisable to understand the basic chemistry of biodiesel production, fuel quality testing, diesel equipment mechanics and fuel system problems. It is advisable to try using homemade biodiesel in older, inexpensive equipment before fueling newer, more expensive equipment. By all means, keep non-ASTM certified biodiesel fuel out of equipment in which the warranty may be voided by its use. Those who own diesel equipment under warranty are advised to check with their manufacturers regarding recommended percentage limits for biodiesel blends.

Good quality biodiesel can be assured if the following conditions are met:

The reaction is complete.

You have to make sure the vegetable/fat oil molecules are completely broken down and the viscous glycerin is free. An incomplete reaction results in unreacted oil left dissolved in the biodiesel. The presence of unreacted oil is determined by dissolving a small amount of the biodiesel in methanol (See Figure 1). If it does not completely dissolve in the methanol, you know the reaction was incomplete. The undissolved fraction determines the rate of conversion, e.g., one out of four parts of biodiesel undissolved in methanol shows 25 percent of unreacted oil. The unreacted products in 100 percent biodiesel should be less than 0.22 percent or 2,200 parts per million. Poorly converted oils/fats have been shown to form gum-like deposits around injector tips and valve heads. The presence of an unreacted product can also affect the cold-flow properties of biodiesel, resulting in gelling at higher temperatures and causing filter plugging and injector damage after long-term use.

The biodiesel is washed well.

Free glycerin is the byproduct of a complete reaction and is laden with the catalyst (lye) used in the process. Both of these along with excess alcohol settle down to the bottom of the reactor before being drained out. Biodiesel is then washed with water to remove any leftover glycerin and catalyst. Glycerin is limited by the ASTM specifications as 0.02 percent. Free glycerin has the potential to form gum-like deposits around injector tips and valve heads while the catalyst/lye can damage the injector pump. It also affects the viscosity of the final product.

The biodiesel is dry enough.

Moisture contents in biodiesel, as leftover from the wash process, can cause corrosion of the engine's fuel system components through rusting. Moisture can also cause the biodiesel to become acidic over time causing corrosion of the fuel storage tanks. Water can facilitate microbial and algal growth leading to storage problems in the tanks. For these reasons, biodiesel is dried enough to reduce the moisture to 0.05 percent.

Other issues to consider when producing and using biodiesel are:

Methanol (or ethanol), the unifying force

As a solvent, methanol keeps biodiesel, glycerin, lye and water together. Removing methanol helps separate glycerin, lye and water from biodiesel, which helps meet the ASTM specifications. Methanol drastically affects the biodiesel flashpoint (the temperature at which it ignites), which is typically more than that of petro-diesel. Biodiesel's flashpoint is about 266 degrees F, while the flashpoint of petro-diesel is about 143 degrees F. For comparison, methanol has a flashpoint of 52 degrees F. As little as 1 percent methanol in biodiesel can lower the flashpoint to less than 100 degrees F, a safety hazard for storage. Residual methanol can directly affect an engine's fuel pumps and seals and can result in poor combustion properties. The ASTM standard hence limits the amount of residual alcohol in biodiesel to less than 0.2 percent, which is too small to affect the fuel's performance.

Biodiesel, a good solvent

Biodiesel has a better solvent potential than petro-diesel. It therefore can clean out fuel tanks, storage tanks and the fuel lines when used for the first time. Biodiesel and its blends act as a detergent and will eventually clean out most of the sediment and sludge that has built up in the fuel system and tanks. Because fuel filters catch most of it, it is recommended that they be replaced more frequently when biodiesel is started initially. Once all the sediment and sludge is out, there is no need to change the filter more than routine maintenance. Starting with lower biodiesel blends can also help alleviate sudden loads on the fuel filters and the engine.

Winter starting

The biggest issue with running biodiesel or even petro-diesel in cold weather is their tendency to gel. Petro-diesel tends to gel between 5 and 40 degrees F, while biodiesel prepared from vegetable oil tends to gel between 26 and 54 degrees F. Petro-diesel fuel is adjusted for the season (winterized) at its distribution point to maintain the cold weather flow characteristics of the fuel. To avoid gelling of biodiesel in cold weather, it must be mixed with winterized diesel in a percentage suitable for that weather and climate. Another way to fix this problem is to add an anti-gel additive. The term "cloud point" is used to describe the temperature at which the fuel turns into gel-like crystals. Cloud point is dependent upon the oil used. Animal fat gels at higher temperatures compared to vegetable oil. The cloud point can be estimated by subjecting a biodiesel sample to a cold temperature (See Figure 3). One way is to put the sample into a clear vial, preferably glass, and churn it around in a bowl containing ice cubes dusted with table salt (the old way of make ice cream in the kitchen). Use a low temperature stem thermometer to note the temperature of the biodiesel when it turns to gel.

Good quality biodiesel ensures excellent engine performance comparable to petro-diesel while providing important environmental and economic benefits to society. There are proven solutions to the problems encountered with using biodiesel, e.g. cold-weather performance, solvent properties and long-term storage. Poor-quality biodiesel, on the other hand, has many negative effects on an engine. To protect against this, it is recommended to use biodiesel that complies with the ASTM biodiesel specifications. Home biodiesel brewers should have their product pass these standards.

Additional information is available at the LSU AgCenter Web site, www.lsuagcenter.com/callegari, and the National Biodiesel Board's site at www.biodiesel.org. ■

Perfect Pair for Biofuel
Switchgrass and Trees

Michael Blazier

Louisiana is one of the top energy-producing states in the nation because of its abundant reserves of fossil fuels like oil and natural gas. Thanks to its long growing season, diverse vegetation, central location and well-developed agriculture and forestry infrastructure, Louisiana has the potential to become one of the top biofuel-producing states as well.

Any fuel derived from plant biomass is considered a biofuel. Ethanol produced from corn and biodiesel produced from soybeans are the top biofuels produced in the United States. The U.S. biofuel market arose from economic and national security concerns. Nearly 2 percent of the nation's gross domestic product is used annually to import oil, and the world's oil supply is expected to decline by 80 percent in the next 50 years because of waning oil reserves and increasing use of oil.

The energy needs of the United States are too high to be met solely by corn ethanol and soybean biodiesel. For example, using the entire 2008 U.S. corn and soybean crops to produce biofuels would meet only 18 percent of the U.S. transportation fuel demand.

Cellulosic ethanol can be made from nonedible parts of plants, unlike conventional corn- or sugar-based ethanol. Forest biomass and grasses such as switchgrass are promising feedstocks for cellulosic ethanol. Forestry contributes $3 billion to $4 billion to Louisiana's economy annually, making it the state's top agricultural commodity. Because of their abundance and high biomass growth potential, Louisiana's forests are logical biofuel feedstock sources. The contribution from forest biofuel production would be relatively sporadic, however, because the major contribution would be at harvest, which is generally when a forest stand is greater than 15 years old.

Switchgrass has many characteristics that make it a desirable cellulosic ethanol feedstock. Switchgrass can be grown with minimal fertilization, and it produces high yields even on marginal soils. It is highly tolerant of flooding and drought and has the potential to produce 1,000 gallons of ethanol per acre, which compares favorably with corn and sugarcane. However, growing a crop dedicated predominately to the relatively new biofuel market carries economic risk.

Agroforestry management systems can be developed to integrate switchgrass and forest production. In such systems, switchgrass would be grown as a biofuel feedstock within alleys between trees. Once switchgrass reaches a near-mature state by its second year, it can be harvested annually. The trees can be harvested occasionally as traditional forest products when they reach merchantable size, and the tree branches can be collected and marketed as biofuel feedstocks.

The diversity in products and vegetation offered by such systems would reduce economic risks associated with entering a new market, maximize yields by optimizing the use of growing space, and improve environmental services such as wildlife habitat, capturing carbon from the atmosphere and storing it in the soil and protecting water quality from nutrient pollution. Several projects are under way in the LSU AgCenter to develop the blueprint for this management system.

At the LSU AgCenter Hill Farm Research Station near Homer, La., studies were established in 2000 and 2008 to determine the feasibility of growing switchgrass in rows between loblolly pine trees. The purpose of these studies is to develop an agroforestry system for producing switchgrass for biofuel in an upland soil typical of north central Louisiana. Switchgrass was planted

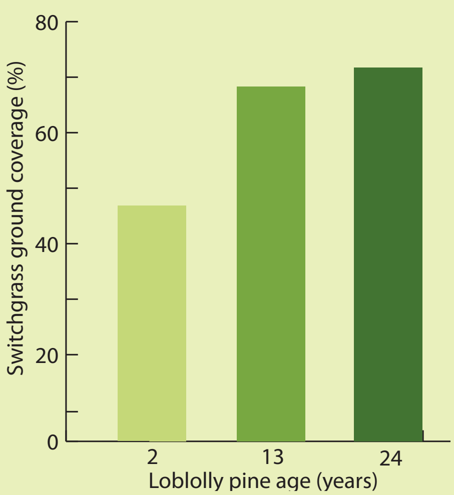


Figure 1. Percent of ground covered by switchgrass five months after planting under loblolly pine of diverse ages.

Figure 2. Percent of ground covered by switchgrass five months after planting without loblolly pine, with a relatively low density of loblolly pine (300 trees per acre for a 2-year-old stand, 100 trees per acre for a 13-year-old stand, 25 trees per acre for a 24-year-old stand) and with a relatively high density of loblolly pine (600 trees per acre for a 2-year-old stand, 200 trees per acre for a 13-year-old stand, 50 trees per acre for a 24-year-old stand).

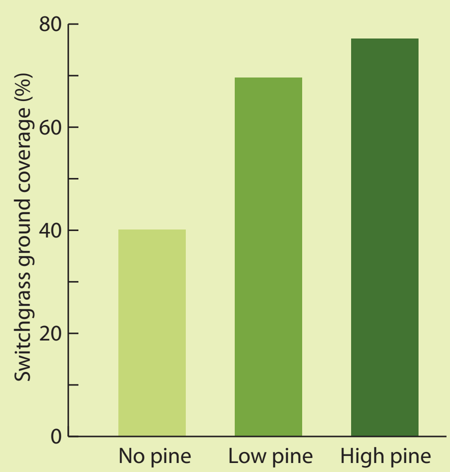


Photo by Mary Ann Van Osdell

between rows of newly planted 2-year-old loblolly pine as well as between the rows of 13-year-old and 24-year-old loblolly pine soon after a thinning – or partial harvest – of the plantations. In all pine plantation ages, switchgrass was established between trees by first applying the herbicide glyphosate, then disking the soil and then broadcast-seeding Alamo switchgrass seed.

Significantly more switchgrass cover was found by the end of the first growing season beneath the older trees than between newly planted loblolly pine (Figure 1). Furthermore, the quantity of switchgrass cover increased with number of trees in the overstory (Figure 2). These results illustrate a beneficial influence of shading on switchgrass establishment. Competing vegetation is an impediment to successful switchgrass establishment because of relatively high variability in the dormancy period of switchgrass seed once in the soil, which allows competing vegetation to become established before the switchgrass germinates. At the Hill Farm site, crabgrass was much more abundant where pine shading was absent than in plots with pine shading, suggesting that the shading provided some competition control for the switchgrass.

The studies at the Hill Farm Research Station have shown that average switchgrass production without fertilization was 2.5 tons per acre per year, with a maximum of 3.5 tons per acre per year. Planting loblolly pine at 300 trees per acre, with row widths of 20 feet to facilitate switchgrass production, has yielded an average of 14 tons per acre of pulpwood by an age-13 thinning operation.

Research on agroforestry systems for Louisiana is expanding. In March 2009, a new study was established near the LSU AgCenter Macon Ridge Research Station in Winnsboro, La., to explore growing switchgrass in alleys between eastern cottonwood trees. The purpose of this study is to develop an agroforest system for producing switchgrass and cottonwood as biofuel feedstocks on a soil characteristic of the marginal-quality soils found within the lower Mississippi River alluvial valley. While the region has abundant soils well-suited to agricultural production, some soils require too much irrigation and fertilization to produce conventional crops profitably. Switchgrass and eastern cottonwood, however, can thrive on such soils with relatively little fertilization and no irrigation. Cottonwood can grow as much as 8 feet in height per year on such soils and can yield as much as 700 gallons of ethanol per acre. Cottonwood and switchgrass were successfully established, and energy yields, water quality and soil properties associated with this agroforestry system will be monitored in coming years. ■

Michael Blazier, Associate Professor, Hill Farm Research Station, Homer, La.

Microwave Technology in Biodiesel Production

Dorin Boldor

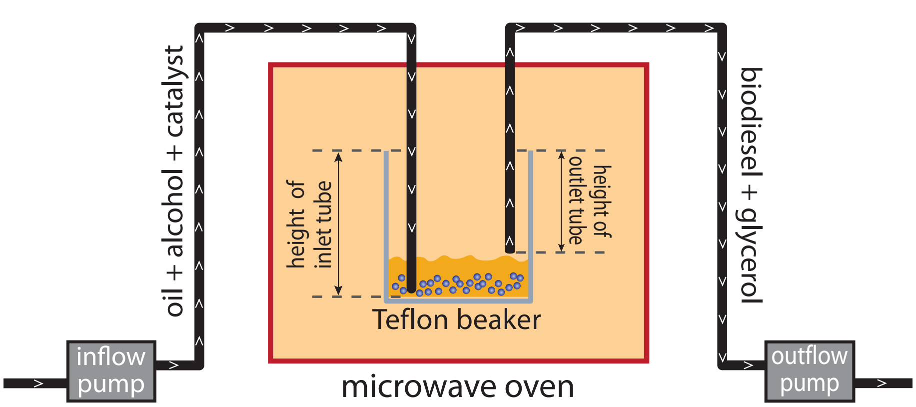
Photo by John Wozniak

LSU AgCenter researchers are investigating production of biodiesel, which has received worldwide attention as a renewable transportation fuel and blending agent. Biodiesel has potential to replace petroleum products, lower net carbon dioxide emissions, which contribute to global warming, and reduce emissions of particulate matter with carcinogenic compounds. Other advantages include portability, improved lubricity, higher flash point (the temperature at which it ignites) for increased safety during handling, the on-site manufacturing (especially for on-farm use), lower sulfur and aromatic content and higher biodegradability. One of the most attractive features of biodiesel is its domestic origin, which would help reduce U.S. dependency on imported petroleum.

Fundamentally, vegetable oils can be directly used in older (prior to the 1980s) or modified diesel engines, but their extended use would lead to poor engine performance and clogging, especially at low temperatures. Therefore, modifying the vegetable oil into biodiesel is essential for successful engine operation over the long term because this process reduces fuel viscosity and fuel-line clogging and improves the combustion process.

Transesterification (also called alcoholysis) is the chemical reaction of one unit of fat or oil (triglycerides) with three units of alcohol in the presence of a catalyst to form esters and glycerol. Because the reaction is reversible, extra alcohol is normally used to prevent reverse reactions. Among the suitable alcohols that can be used in the transesterification process, methanol and ethanol are used most frequently, especially methanol because of its low cost and its physical and chemical advantages.

Figure 1. A schematic representation of the continuous microwave biodiesel system.



The catalyst can be a base, acid or enzyme, depending on oil quality, but most industrial processes use base catalysts – either sodium hydroxide or potassium hydroxide (lye) – because they act more rapidly with lower operational costs.

Base-catalyzed transesterification occurs at 140 degrees at atmospheric pressure, and it takes one hour using traditional heating sources. Recently, however, researchers discovered that microwaves used as a heat source, can decrease reaction time to less than two minutes, significantly reducing the costs of biodiesel production. This reaction can be performed continuously in a specially adapted microwave oven, with the possibility of controlling the reaction using a fiber optic temperature system.

The efficiency of microwave-assisted transesterification stems from the unique properties of the mixtures of vegetable oil, solvent and catalysts. In normal heating with an open flame or electric heater, energy is put into the system via conduction and convection through the different layers of liquids, and a mixer is needed to enhance the reaction rate through increased contact between fat and alcohol molecules. As such, the heating is relatively slow at the molecular level – each molecule has to get its thermal energy from the neighboring molecules and then patiently try to encounter its molecular counterpart in order to react.

In microwave irradiation, by comparison, rapid heating occurs because of direct energy absorption in the whole volume of the mixture. Microwave energy interacts with the material on a molecular level, generating inter-molecular friction and molecular mixing and agitation that increase contact between alcohol and oil molecules.

The reaction occurs at the same temperature, pressures and other operational parameters as in the normal transesterification, but special care and safety measures need to be observed when using the microwave process. In general, researchers strongly recommend against modifying home microwave ovens because microwaves can be extremely dangerous if they leak out of the system. In addition, home microwaves are not made to support the use of temperature measurement systems nor are they provided with a microwave power feedback control system. Therefore, the control of the reaction is extremely difficult, and the operation can become hazardous. The use of an industrial/commercial apparatus specially designed for this purpose is, therefore, mandatory.

Figure 1 presents a schematic version of the continuous system. In practice, a commercially available, fully instrumented, batch-type microwave system is modified to make it operate continuously. The setup includes a 2-quart cylindrical Teflon beaker acting as the reaction vessel in the center of the microwave application chamber and Teflon tubing serving as inflow and outflow conduits. Before the reaction, a catalyst (sodium hydroxide) is dissolved in alcohol, and the mixture is added to the oil (in a ratio of approximately 20 percent alcohol and 80 percent vegetable oil by weight) and mixed before being pumped into the microwave system.

The time in the chamber will depend on the flow rate and the volume of sample at any given time. The reaction temperature is monitored with a fiber optic probe and automatically controlled by the system. A magnetic stirrer maintains additional agitation in the chamber. The recommended time in the chamber is five minutes, even though one to two minutes are usually enough to complete the reaction. Glycerin separation and biodiesel washing, drying and solvent recovery follow the same recipe as in conventional biodiesel production process.

Quality analysis is performed similarly to other biodiesel production processes and includes determination of cloud point, flash point, viscosity at 104 degrees, acid number, oxidation stability index, free and total glycerin and free fatty acid composition. For example, LSU AgCenter researchers have determined that total and free glycerin and conversion rates of soybean and rice bran oil into biodiesel using this method meet the American Society for Testing and Materials (ASTM) requirements at reaction times as short as one minute and at temperatures as low as 122 degrees F. Cloud point, flash point, viscosity, acid number and oxidative stability index measured for the biodiesel made using the microwave-assisted technology met or exceeded the ASTM standard specifications. ■

Dorin Boldor, Assistant Professor, Department of Biological & Agricultural Engineering, LSU AgCenter, Baton Rouge, La.

Callegari Center's Biodiesel Quality Control Lab

The LSU AgCenter's W.A. Callegari Environmental Center has established a well-equipped laboratory to perform biodiesel quality control analyses for a nominal charge. Biodiesel producers are encouraged to test their biodiesel fuel for quality assurance. All the analyses are performed according to the standards of the American Society for Testing and Material (ASTM) procedures. Analytical results are compared with the ASTM biodiesel specifications (called D6751). For a listing of all the analyses the Callegari Center can perform, go to the LSU AgCenter's Web site and search for Callegari Center. Besides these analyses, the center is capable of analyzing feedstock for biodiesel potential.

In March 2008, the center began offering training on the basics of biodiesel production. The training involves basic chemistry and knowledge of the whole process, necessary hardware and chemicals, process monitoring, safety, and economics. This hands-on experience equips trainees with sufficient understanding to start making their own biodiesel. Another important aspect of the training is demonstration of biodiesel production using a fully automated processor and a manually operated processor. Areas of research at the center include production techniques, feedstock sources and analytical techniques.

■ **Linda Foster Benedict**

Chinese Tallow Trees
As a Biodiesel Feedstock

Gary Breitenbeck

Biodiesel derived from renewable vegetable and animal fats is attractive as a substitute or additive for petroleum diesel because of its high energy return, simplicity of manufacturing, high lubricity and capacity to substantially reduce most exhaust pollutants. Currently, biodiesel production is severely limited by the availability of affordable feedstocks. The price of soy oil, the mainstay of the U.S. biodiesel industry, has risen beyond the point where biodiesel can compete with petroleum diesel, even with a $1 per gallon federal subsidy. To significantly affect our dependence on petroleum diesel, development of high-yielding alternative oilseed crops is essential. To minimize the effect of biofuel production on the world's food supply, these crops must be adaptable to land not currently used for food production.

The Chinese tallow tree is perhaps the most promising oilseed crop adapted to the humid South and capable of producing a sufficient supply of feedstock to meet the needs of the U.S. biodiesel industry. The Chinese tallow tree is an introduced species that grows rapidly, spreads profusely and has become naturalized along the Gulf and southern Atlantic coasts between Texas and North Carolina where it is considered a noxious weed. It is also found in California.

In China, where this tree has been cultivated for more than 1,500 years, it is used to stabilize levees and stream banks. It also provides fertilizer to rice crops and is harvested for its oilseed. The seed of the tallow tree produces two distinctly different types of lipids – or fats – a nontoxic "tallow," external to the seed coat, and a mildly toxic kernel oil, commonly called "stillingia oil."

In China, the tallow tree is reported to be grown without industrially produced fertilizers or pesticides, yet it is capable of producing 750 or more gallons per acre of waxes and oils used for multiple purposes, including lighting and heating oils, soaps and pharmaceuticals, as a substitute for cocoa butter in chocolate, and to produce dairy creamer substitutes. Other reports claim the tallow tree in managed systems is capable of producing seed yields of 12,500 pounds per acre, which contain about 300 gallons of kernel oil, 6,200 pounds (about 180 gallons) of tallow, 3,300 pounds of protein meal suitable for use as fertilizer, and 13 tons of fibrous and hard seedcoat.

LSU AgCenter scientist have confirmed that Chinese tallow trees growing in favorable environments in Louisiana are capable of extraordinary yields. Hand harvesting of a single tree with a drip-line area of 380 square feet produced 68 pounds of seed. By extrapolation, this represents a seed yield of more than 7,800

Photos by Gary Breitenbeck

Two years after transplanting, this Chinese tallow tree has grown to nearly 16 feet. The trunk diameter has increased from 1.1 to 5.1 inches, demonstrating the potential of the trees to sequester carbon. The tree is heavily laden with flowers and will produce a harvestable crop in its third season.

A typical tallow tree two years after transplanting as a 1-year-old sapling. This tree has not yet produced flowers. Joe Kraska, in the photos, is a graduate assistant in the LSU AgCenter pounds per acre containing 4,000 pounds of tallow and 3,750 pounds (about 420 gallons) of kernel oil. With appropriate management and continued research and development, sustainable yields of this magnitude are conceivable in commercial production.

These high yields can lead to misconceptions regarding the amounts of seed produced in naturalized stands. In a half-acre area located in a highly dense stand of naturalized tallow trees, trees were scored based on seed load from zero to 4 for exceptional. The average score was 1.2, with most trees producing no seeds or only a few seeds at the top of the canopy. Rarely did a tree produce seeds throughout the canopy. Low seed yields are common when the tallow tree is heavily self-shaded or growing as an understory tree in a mixed forest. Even when provided with adequate light and water, however, most naturalized trees produce low amounts of seeds.

In a count of tallow trees growing in the fence row surrounding a pasture, only 27 percent were ranked as good or better. Seed production was considered exceptional in only one of 124 trees. In contrast to naturalized trees, nursery stock planted in full sun with adequate water and nutrients frequently produces high seed yields. In one stand of 12 landscape trees, seed production of every tree was rated good or exceptional.

Naturalized trees generally produce greater seed yields when growing along stream banks or drainage channels. While they tolerate continual flooding, they seem to produce better when flooded intermittently. Tallow trees are also extremely salt-tolerant. One tree with an exceptional seed load was growing in soil considered too saline for all but the most salt-tolerant plants. Shallow, less-saline groundwater may have benefited this tree.

Tallow trees are seldom found on drought-prone soils or in undisturbed mature forests. Fertility requirements are largely unknown, though limited evidence suggests they are low. These trees apparently attract few insects, and these few do not appear to affect the trees adversely. The trees develop occasional leaf lesions from fungal or bacterial infections, but these infections are invariably mild, affecting only a few leaves. The most common disorder of the tallow tree foliage causes cupping and dwarfing of leaves, usually near the base of the tree. This disorder does not appear to significantly affect tree health or productivity, however. The cause of this malady is under investigation.

Clearly, both genetics and environment interact to influence yields. LSU AgCenter researchers are documenting the differences in a random sampling of saplings collected across the Gulf Coast region and transplanted to a uniform environment. Only one or possibly two of these trees have displayed commercial potential. A primary research goal is to establish similar plantings of exceptional trees selected from the naturalized population. Because of the time required to breed and evaluate trees, collections are concentrating on “elite” ecotypes that display high yields and other characteristics desirable for commercial production.

A three-year investigation has demonstrated that that the tallow tree has legitimate potential to supply the biodiesel industry with critical feedstock at low cost. Tallow trees readily adapt to soils too infertile, wet or saline for profitable agriculture; therefore, commercial production will not compete with food crops for limited land resources. Because of their high yield potential and oilseed value, tallow trees offer the possibility of restoring economic prosperity to some of the most impoverished areas of the South. For example, tallow trees continue to thrive in Plaquemines Parish,in the very southern tip of Louisiana, where soil salination caused by recent hurricanes has damaged the citrus industry. ■

Gary Breitenbeck, Professor, School of Plant, Environmental and Soil Sciences, LSU AgCenter, Baton Rouge, La.

(A longer version of this article is posted on the LSU AgCenter Web site. Go to LSUAgCenter.com and click on Louisiana Agriculture Magazine.)

Potential of **Nonmarketable Pecans** for Biodiesel Production

Gary Breitenbeck, Charles Graham and Javed Iqbal

The expansion of the U.S. biodiesel industry in the past few years has been astounding. Biodiesel production increased from 0.5 million gallons in 1999 to 450 million gallons in 2007. The combined capacity of existing U.S. biodiesel facilities exceeds 2.2 billion gallons with an additional 1.2 billion-gallon capacity scheduled to be completed by the end of 2010. The U.S. biodiesel industry is now suffering from acute growing pains as production capacity has outpaced the supply of suitable vegetable oil to produce biodiesel.

Recent data from the National Biodiesel Board suggest U.S. biodiesel facilities have operated at about 20 percent capacity because of a lack of affordable feedstocks. Feedstock accounts for 70-80 percent of the cost of biodiesel production, and its cost is the principal factor determining the competitiveness of biodiesel with petroleum-derived diesel. Soy oil has been the feedstock of choice, but high soybean oil prices have caused many U.S. biodiesel refineries to halt operations or to shift to alternative feedstocks such as animal fats and waste cooking oil. It is far more difficult to process these alternatives into biodiesel that meets rigorous American Society for Testing and Materials (ASTM) standards. There is a critical need to identify additional affordable feedstocks to preserve the fledgling U.S. biodiesel industry.

One answer may be pecans. Pecan nuts contain a high amount of oil consisting primarily of oleic acid, a fatty acid well-suited for biodiesel production. But planting pecans for biodiesel is impractical for several reasons. It takes a decade or more for a young pecan tree to begin producing nuts. And given their high value as a foodstuff, the nuts are too valuable to be crushed for oil. Even so, significant acreage of both wild and

Continued on page 35

Winter Cover Crops
As Alternatives for Biodiesel

Gary Breitenbeck, Joe Kraska and Javed Iqbal

Biodiesel, a biofuel derived from vegetable and animal fats, burns more cleanly than conventional diesel in modern diesel engines. It also provides superior lubricity and reduces our dependence on fossil fuels. Because biodiesel is derived from vegetable and animal fats, it does not contribute to increased carbon dioxide in the atmosphere normally associated with fossil fuels – the carbon released by burning biodiesel is assimilated into the next year's crop.

Soybean oil has been the feedstock of choice for biodiesel production in the United States. As a consequence, soybean oil prices have correlated with the price of crude oil since the rapid expansion of the U.S. biodiesel industry over the past several years. Soybeans contain about 20 percent oil by weight. The high-protein meal that remains after oil extraction is used largely for animal feeds. Until recently, this meal was considered the most valuable component of soybeans. The rapid increase in production of soy biodiesel has created a shortage of oil and a dramatic increase in its value. In July 1999, the price of soy oil was $1.21 per gallon – less than the price of a gallon of diesel fuel. At its peak in July 2008, soy oil sold for $4.60 per gallon. While prices have declined since, they remain more than twice those of 2006. High soybean oil prices have caused some U.S. biodiesel refineries to halt operations or to seek alternative feedstocks.

The diversion of soybeans and other staple foods to biofuel production has been blamed for increasing food costs and global food shortages. Substituting nonfood cultivated crops such as rapeseed for biodiesel is not an entirely satisfactory alternative because these alternative crops also are claimed to contribute to a reduced food supply and high food prices by competing with food crops for land and water resources.

Some also claim biofuel production leads to increased environmental pollution. It is true that when prices of soybeans and other crops are high, marginal land is brought into production. In some instances, drainage and cultivation of these marginal lands can increase soil erosion and surface water pollution. Weighing the positive and negative effects of biofuels, many experts conclude that some types of biofuels have a place in a diverse portfolio of renewable energy sources designed to reduce our dependence on fossil fuels.

The case for pursuing biodiesel is perhaps stronger than that for gasoline substitutes. Wind, solar and most other renewable alternatives produce electricity, not liquid fuel used for transportation. While replacing gasoline-powered internal combustion engines with electric motors is an attractive alternative for personal vehicles, pumps and other stationary engines, electric power is a less viable alternative for tractors, construction equipment, commercial transportation and other mobile applications requiring high torque and horsepower. Diesel engines have few alternative fuels other than compressed fossil fuel gases – for example, liquefied natural gas – and biodiesel, a renewable fuel.

The critical need for low-cost oilseeds suitable for biodiesel production has stimulated research for a new generation of oilseed crops, many of which will not tolerate freezing conditions. Frost occurs across most of the United States, though the mild winters of the South allow the use of more hardy "winter" crops, some of which are capable of producing oilseed. It is generally recognized that winter cover crops can be grown successfully to improve soil fertility and mitigate soil erosion and pollutant runoff associated with cultivated agricultural fields. Although economically and environmentally sound, the use of winter covers is not widely practiced, in part because the benefits are generally not perceived as sufficient to offset risks. As a result, many millions of acres of prime agricultural land sit idle during winter months.

In 2008, the LSU AgCenter initiated a study to identify cool-season cover crops with potential as second crops. These initial studies of planting date included three plants of the mustard family – oilseed radish, a white mustard variety (Ida Gold) and an Indian mustard variety (Pacific Gold). While many species merit evaluation within this family, these three were selected because they have successful histories as cover crops, and seed is readily available. Each of these crops is known to be tolerant of light frost, provide dense cover to suppress weeds, and use residual soil nutrients remaining after harvest of the principal crop.

Oilseed radish is considered a winter forage crop because it is low in glucosinolates – organic compounds that contain sulfur and nitrogen. Ida Gold and Pacific Gold, on the other hand, contain high levels of glucosinolates and are thus not palatable to most foraging animals. Glucosinolates have an additional benefit. They decompose in soil to form biologically active compounds that behave as fumigants to repress nematodes and other crop pests.

In LSU AgCenter studies, oilseed radish germinated early and produced consistent, dense stands that seemed to be unaffected by drought, cold or insects. Unlike the mustard crops, oilseed radish produced tall, branched stems that lodged – or fell over – several weeks before maturity. Uneven maturity; large, thick pods with small seeds; and a tangled, lodged stand suggest that harvesting with a combine will be difficult and inefficient. Improved varieties are needed before this robust plant can be grown successfully as a winter oilseed crop.

Both Ida Gold and Pacific Gold produced upright plants suitable for machine harvesting, though the seed of Pacific Gold was distributed throughout the plant, whereas Ida Gold seeds were concentrated near the top where they can be harvested more easily. Stands of the two mustards were highly inconsistent, ranging from none to excellent – a result of a combination of unusually dry soil conditions and cold temperatures in the fall of 2008. Pacific Gold failed to germinate until irrigation was applied. Late plantings of this variety in December and January grew poorly until temperatures warmed in spring. Most stands of Ida Gold showed more severe damage from chewing insects that those of Pacific Gold, though Pacific Gold matured earlier.

When planted between mid-October and late November, Pacific Gold matured between the first and third weeks of April. Ida Gold matured about two to three weeks later. Early maturity is a critical attribute for second crops to ensure timely harvest and adequate time to prepare fields for the summer crop. Both mustards were infected by powdery mildew before maturity, but these infections were mild and did not appear to influence yield. Oilseed radish began to mature in late April, and some late-planted plots had not fully matured by mid-June.

Yields varied greatly, primarily because of differences in stand caused by dry, cold conditions that persisted for most of the winter. Seed yields averaged over all planting dates were 1,188 pounds per acre for oilseed radish, 904 pounds per acre for Indian mustard and 440 pounds per acre for white mustard. The highest seed yields were obtained when these crops were planted at the earliest date – Oct. 15 – when oilseed radish averaged 2,403 pounds per acre, Indian mustard averaged 2,756 pounds per acre and white mustard averaged 665 pounds per acre.

The maximum oil yield was about 143 gallons per acre with Pacific Gold. The lowest oil yields came from Ida Gold because of lower seed yields and oil content. Seed oil composition was similar to that of rapeseed, another member of the mustard family widely used for biodiesel in Europe.

Seed and oil yields were sufficiently high to suggest further studies to develop production systems that integrate winter cover crops as harvestable oilseed crops. No clear choice has emerged from three varieties evaluated, though early maturity, high oil content, suitability for combine harvesting and adequate pest resistance indicate the Indian mustard Pacific Gold merits further consideration as a winter oilseed crop for the humid South.

When planted as early as practical in the fall, some of the tested winter oilseed crops matured by early April, allowing sufficient time to prepare fields for most summer crops. Potential oil yields are greater than those of soybeans, largely because the seeds contain a higher percentage of oil. Unlike soybeans, however, the meal of mustards is not likely to be of significant market value as animal feeds. The meal's principal value may be as an organic fertilizer or for ethanol production.

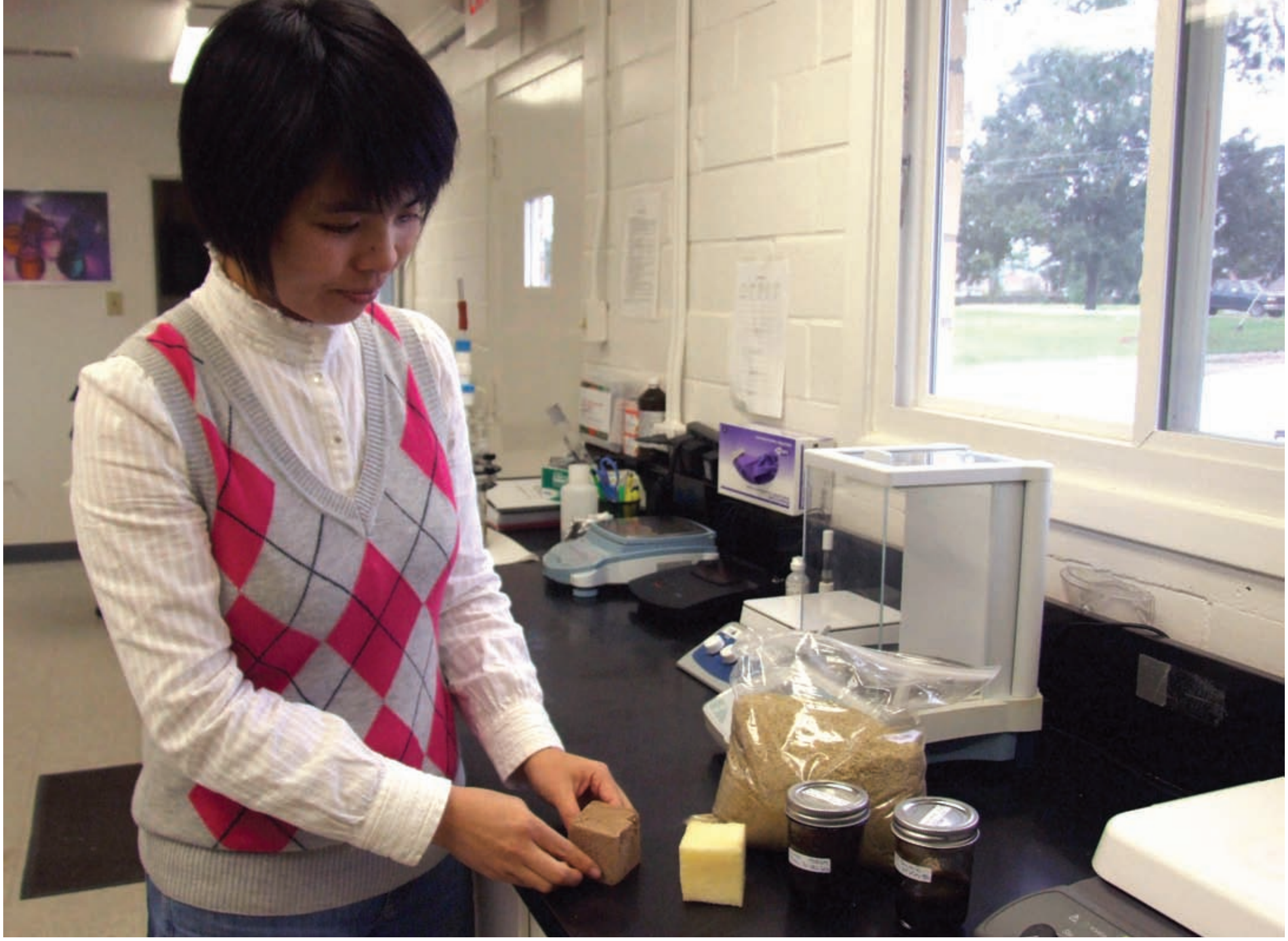
A principal advantage of these crops is they use prime agricultural land during a period when this land is not used to produce conventional food crops. Millions of acres of land in the Southeast are winter-fallowed – sufficient to have a significant effect on the supply of feedstock for biodiesel production.

Additional research is needed to identify the ideal varieties and production practices and to firmly establish the economic benefits of growing winter cover crops for oilseed. The potential of oilseed radish as a winter biomass crop also merits further study. ■

Gary Breitenbeck, Professor, and Joe Kraska, Graduate Assistant, School of Plant, Environmental & Soil Sciences, LSU AgCenter, Baton Rouge, La.; Javed Iqbal, Laboratory Manager, W.A. Callegari Environmental Center, LSU AgCenter, Baton Rouge, La.

Photos by Gary Breitenbeck

Top photo: oilseed radish
Bottom photo: Indian mustard
Background photo: winter cover crop test plots at LSU AgCenter



Hui Pan, assistant professor at the Calhoun Research Station, holds samples of polyurethane foam made from liquefied wood. The foam is free of heavy metals and safe for the environment.

Wood Liquefaction

and Value-Added Products

Hui Pan and Todd F. Shupe

Using biomass as an alternative to petroleum-based products for fuel has attracted interest because of its biodegradable nature and renewable properties. Biomass conversion to liquid and gaseous products has potential to provide a wide range of bio-based energy, fuels and chemicals. Thermochemical conversion, including pyrolysis, liquefaction or gasification, is a main route of biomass utilization that results in biofuels and valuable bio-based chemicals.

Liquefaction refers to two different types of processes – direct liquefaction, which is similar to pyrolysis but conducted under lower temperature and pressure, and solvolysis liquefaction, in which biomass is dissolved in an organic solvent. The term wood liquefaction refers to solvolysis liquefaction.

Wood is a natural polymer consisting of three main components – cellulose, hemicellulose and lignin. Cellulose is a linear polymer of glucose units and can be thought of as one kind of sugar. Hemicellulose is similar to cellulose and bonds to cellulose to form a network of cross-linked fibers. Lignin is generally referred to as the “glue” that holds wood together. For example, lignin must be removed in the pulping process to separate the wood fibers and produce high-quality paper. Lignin is tightly bonded with the other wood components and provides the supporting and strengthening material in wood.

In 1946, a process was patented to convert bio-based materials containing lignin and cellulose, particularly bagasse, into a phenolic-based wood adhesive by reacting the material under elevated temperature and high pressure in the presence of phenol and sulfuric acid. Because phenol formaldehyde resins are derived from petroleum, which at the time was abundant, this approach was not adopted by the industry.

Fast forward to the 1980s when the global marketplace started to undergo demand for “greener” bio-based products in many developed nations, increased mechanization in underdeveloped countries, and an overall increasing human population with a corresponding demand

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for traditional fossil fuels. The 1980s saw many patents and research papers published about wood liquefaction and its applications for adhesives and moldings and even as a means to develop foam-based products.

Most methods for wood liquefaction include methods that use catalysts and those that do not use catalysts. A catalyst is a chemical added to increase the rate of the reaction. During liquefaction, wood is converted into a viscous liquid. Almost all sources of biomass – trees, bark, corn stalks, bagasse, etc. – can be liquefied successfully.

Indeed, many studies have been conducted to establish the basis of the liquefaction process and its application for various products; however, research on many fundamental aspects is still lacking. Research on wood liquefaction has been ongoing at the LSU AgCenter since 2003. This research involves both improvement and refinement of the liquefaction process and applications of liquefied wood for value-added products.

Because wood is a complex bio-polymer consisting of different components, liquefaction is a complicated process. Figure 1 shows liquefied wood that has undergone reaction with an organic solvent and an acid catalyst at 320 degrees F for 120 minutes. The solid wood powder has been converted into a viscous, dark-brown liquid.

A residue of solid wood always remains after the reaction, and characterization of liquefied wood residues provides a new approach to better understand some fundamental aspects of the wood liquefaction reaction. LSU AgCenter studies of the residues have shown that lignin is the easiest of the three main wood components to liquefy. The liquefaction rate of the three components is, in decreasing order – lignin, hemicellulose and cellulose. In general, a reaction comprising a higher reagent-solvent-to-wood ratio, longer reaction time, higher liquefaction temperature and stronger-acid catalyst will result in less wood residue.

Strong acid catalysts in the reaction, however, may require special equipment to prevent corrosion, and phenol is the most expensive raw material for liquefaction. Therefore, it is desirable to substitute wood for phenol as much as possible in the process of liquefaction. One significant difference of the weak-acid catalyzed system compared with the strong-acid system is the high residue content, indicating incomplete liquefaction.

Photo by Chung-Yun Hse

Figure 1. Wood particles (left) and liquefied wood (right) being poured into a beaker.

The commercial application of liquefied wood depends on the reagent solvent used in the liquefaction. Wood liquefied with phenol can be directly developed into molded products or used to produce phenolic resin or foam. Phenolic resin is a leading adhesive for composite panels in moisture-sensitive applications, such as oriented strand board and plywood used for sheathing.

Wood liquefaction is a key technological area being explored in conjunction with the closed-loop recycling program at the LSU AgCenter's Calhoun Research Station, particularly with regard to chromated copper arsenate-treated wood. When recycling utility poles, some of the poles will be too severely decayed or damaged to be sawn into lumber or otherwise machined. This material and the sawdust generated from sawing sound poles can be used as a feedstock for the liquefaction process.

The process allows for the wood and heavy metals in the preservative to be recovered separately. This has potential for rural economic development because it can be easily integrated with other recycling methods such as re-sawing of spent chromated copper arsenate-treated utility poles. And more than 95 percent of the heavy metals in the preservative can be recovered. Moreover, this is a "green" technology that can reduce the volume of preservative-treated wood in landfills and help maintain the viability of the preservative-treated wood industry. Poles represent a high-value, downstream product for private, nonindustrial forest landowners, and a strong wood preservation industry helps ensure that private nonindustrial forest landowners receive top dollar for their pole-sized timber.

Research on wood liquefaction at the Calhoun Station includes developing value-added products from liquefied wood and scaling up the application of liquefied wood for resin and foam products. ■

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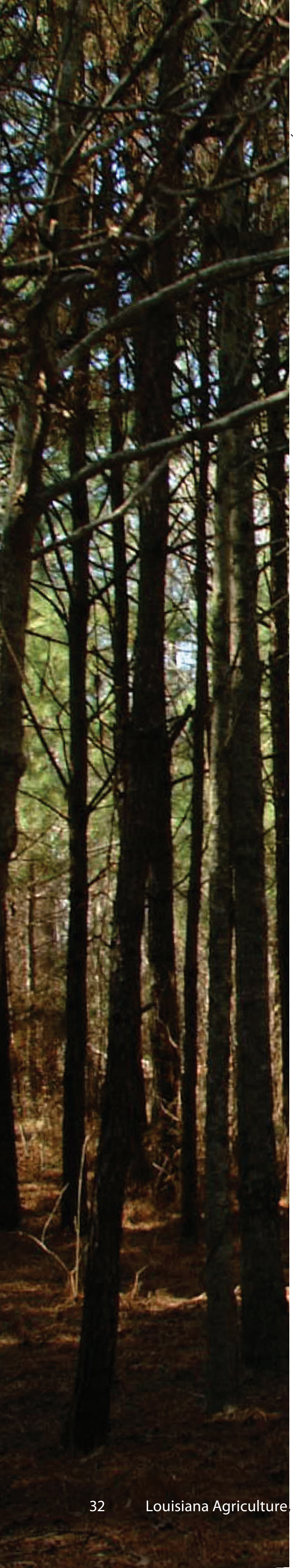

Photos by John Wozniak

Hydrothermal Processing of Plant Biomass for Petrochemical and Bioenergy Products

Todd F. Shupe

Through hydrothermal processing, plant biomass can be converted into energy and petrochemical products. Hydrothermal treatment involves a chemical reaction conducted in water, which has been heated and pressurized in the absence of dissolved oxygen. Water under these conditions has unusual properties, and a mixture of water and biomass can rapidly be transformed to a product that contains many of the long-chain hydrocarbons present in modern combustible fuels.

Hydrothermal conditions provide for reactions not achievable in other common treatment settings. Hydrothermal systems allow biomass conversions into industrially useful or energy-yielding chemical mixtures in configurations that allow for (1) recovering carbon, (2) detoxifying many polluting organic chemicals, (3) recovering elements, such as toxic metals, and (4) recycling heat and water in a closed-loop configuration.

Previous hydrothermal transformation studies were generated under simple reaction conditions – the materials were mixed with tap water, sealed in a metal reactor vessel and treated in heated water under pressure, with no added reactants or catalysts. The intentions were to estimate gas-phase and semi-volatile hydrocarbon yields and identify the most abundant hydrocarbons generated in this process. Research has demonstrated the technical applicability of hydrothermal processing for a wide range of plant biomass types, including invasive plant species and preservative-treated wood waste, both of which have little or no economic value and represent enviromental and ecological problems.

Detoxify preservative-treated wood

Currently, most decomissioned, preservative-treated wood is disposed of in landfills. This option is neither environmentally friendly nor economically advantageous for those disposing large volumes of treated material – for example, the utility and telecommunication industries. Because nearly half of all southern pine is preservative-treated, it is important for Louisiana forest landowners that the wood-preservation industry remain solvent so forest landowners can obtain maximum value for their timber.

Research has looked extensively at the feasibility of hydrothermal processes to detoxify preservative-treated wood. The preservatives of interest have included chromate copper arsenate (CCA), creosote and pentachlorophenol (penta). LSU AgCenter researchers have found that during treatment, creosote-derived hydrocarbon residues in the wood were nearly completely recovered, and the wood itself was transformed into a mixture of hydrocarbons.

These wood-derived transformation products served to reconstitute the “light end” of the creosote, which largely had been lost via leaching while in service. Thus, the hazardous waste of the creosote-hydrocarbon mixture was recovered, and the solid waste wood was transformed into a complementary product mixture in a single pass. For the CCA- and penta-treated wood studies, wood particles were transformed into liquid and gaseous hydrocarbon mixtures irrespective of pH conditions and preservative.

It is cumbersome to segregate decomissioned, preservative-treated wood by preservative type. Therefore, a successful recycling method must accommodate mixtures of wood treated with different preservatives. Accordingly, research is looking at the technical feasibility of

. . . research is looking at the technical feasibility of hydrothermal treatment of equal parts of wood treated with CCA, creosote and penta.

hydrothermal treatment of equal parts of wood treated with CCA, creosote and penta. The initial data have shown that during hydrothermal treatment, the creosote-derived hydrocarbon residues were recovered in the decommissioned, treated wood, and the wood itself was transformed into a mixture of industrially useful hydrocarbons. The metals from the CCA-treated wood were partially recovered, and some arsenic may have been transformed into a gas, which could be trapped and recovered. The penta was detoxified.

The hydrothermal process also generated industrially useful mixed hydrocarbons with a substantial reduction in mass. Thus, the preservative-treated wood was transformed into a liquid mixture that contains many products, of which some can be used for bioenergy and others for bio-based chemicals. It is important to note that this work was performed in large reactors heated with hot air in a muffle furnace. Hence, the incubation time was long. Current work with small reactors heated rapidly (under two minutes) has confirmed that hydrothermal reactions occur within seconds to minutes.

Treat invasive aquatic plants

This work examined hydrothermal treatment of three invasive aquatic plants – lemna, hydrilla and eichhornia. Identical hydrothermal treatments yielded similar semi-volatile product mixtures for hydrilla and eichhornia and a significantly different mixture for lemna. No semi-volatile hydrocarbons were found in any of the species before hydrothermal treatment. Post-hydrothermal treatment product mixtures were composed of complex mixtures of compounds.

Hydrothermal product mixtures from all three plants were dominated by compounds found in the top 100 industrially useful chemicals. Wet chemical analyses showed that a major difference between lemna and the other two plants was that lemna had significantly higher levels of extractives. This fraction accounted for much of the complexity in the post-hydrothermal treatment liquid of the lemna. For all hydrothermal treatments, the mass was reduced by 95 percent or more.

Chinese tallow tree for biofuel

The tree investigated is the Chinese tallow tree. This species is extremely well-adapted to numerous environments, and no known diseases debilitate it. Also, it produces above-ground biomass at a significantly faster rate than most other tree species and is able to establish a dense stand quickly.

LSU AgCenter research has explored the potential of Chinese tallow tree components – wood, bark, leaves and seeds – as raw materials for bio-based chemical and energy production using hydrothermal conversion. Both whole and ground seeds were hydrothermal-treated. Ground wood/bark, leaves and seeds yielded similar aromatic compounds after treatment. Ground seeds yielded unique, minor byproducts and did not contain naphthalene, which was present in the other tissues. Whole hydrothermal-treated seeds yielded a material that resembled asphalt in appearance, odor and chemical properties but did not produce any phenol. In contrast, ground seeds did not yield any particulate matter and had substantial amounts of phenol. The hydrothermal treatment had a fairly neutral effect on energy content of the tallow seeds. The energy values of the tallow seeds are much higher than those typically reported for hardwood stemwood.

In recent years, AgCenter reserchers have documented the transformation of underutilized biomass into gas-phase and semi-volatile hydrocarbon mixtures in hydrothermal reaction systems. Hydrothermal systems can convert biomass into industrially useful or energy-yielding chemical mixtures in configurations that allow for the recovery of carbon as volatile and semi-volatile petrochemicals, the transformation of many polluting organic chemicals, the recovery of elements including toxic metals, and the recycling of heat and water in a closed-loop configuration.

These studies have documented efficiencies on the order of 90-99 percent, and the generation of salable and value-added volatile and semi-volatile compounds, including more than a dozen chemicals in the top 100 commercial petrochemicals. ■

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Microalgal Biodiesel

the Potential and Barriers

Chandra Theegala

Despite successful production and use of vegetable oil-based biodiesels, the contribution of these alternative fuels (including virgin oil, used cooking oil and animal fat) to the overall transportation fuel scenario is fractional at best. Biodiesel production accounts for about 1 percent of the 50-60 billion gallons of diesel needed annually in the United States. This amount is small primarily because of limitations in the production and availability of oil feedstocks, which are linked to the low energy density of traditional oilseed crops. Microalgae, on the other hand, produces lipids (or oils) at an energy density several orders of magnitude higher than traditional oilseed crops such as corn and soybeans. Microalgae are microscopic cells as contrasted with algae, which include larger plants like kelp and seaweed.

Like most vegetable oils, the microalgal oils can be easily converted (transesterified) to biodiesels by reacting with about 10 percent alcohol in the presence of a catalyst such as lye. According to one estimate, growing microalgae as a fuel-producing crop would require only 5 percent of existing U.S. crop acreage to meet 100 percent of present transportation fuel needs. This is compared to 1,700 percent of existing U.S. crop area under corn and 650 percent of existing U.S. crop area in soybeans.

With no commercial facility producing microalgal lipids on a continuous basis, estimates and educated projections from smaller cultures are the only means to assess the potential of microalgae as a fuel source. These estimates vary significantly. They range from 600 to 15,000 gallons per acre per year. The disparity can arise from variations in species, culture conditions, nutrients, environmental conditions, mode of operation (batch or continuous) or type of culture (open or sealed photobioreactor). Based on a U.S. Department of Energy's Aquatic Species Program report, one could assume conservatively that microalgae with a 20 percent lipid content could produce about 2,000 gallons of oil per acre per year. Certain algal species have been reported to have lipid contents as high as 60 percent, which could yield 6,000 gallons per acre per year.

With the lowest microalgal lipid yields beating every known yield from land-based oilseed crops, the potential of microalgae is definitely worth further exploration. Several barriers to successful mass production must be overcome, however. These include:

- Cost-effective harvesting.
- Cost-effective and environmentally benign lipid extraction.
- Culture stability and contaminant mitigation in large unprotected ponds or raceways.

Assuming the same conservative annual lipid productivity figure of 2,000 gallons per acre generated from 100 harvests per year, calculations reveal that the entire volume of 1 acre of culture water, at about 2 feet deep, has to be harvested to yield 20 gallons of oil. Revenue from these 20 gallons of oil must account for pond/photobioreactor capital costs, nutrients, maintenance costs, harvesting costs and lipid extraction costs. Cost-effective harvesting and lipid extraction are perhaps the most critical needs in the area of microalgal lipids. Without advances in these areas, it will be difficult for microalgae to compete with fossil diesel or soybean oil, which sell for about $2.50 to $3 a gallon. Until the technological advances are made or until the economic scenario changes, the huge potential of microalgae may remain commercially untapped.

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The solution to the high microalgal oil production costs may also come from other or nontraditional approaches. For example, genetic research may one day permit accumulation of high concentration of lipids in filamentous microalgae, which traditionally have very low lipid contents but are fairly easy to harvest. A biorefinery model, where high value nutraceuticals or co-products are produced along with microalgal oils, may offer promise by tilting the economic balance. ■

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Background Photo by NSF Polar Programs

Potential of **Nonmarketable Pecans** for Biodiesel Production

(Continued from page 27)

improved pecans is not harvested and marketed as food. In addition, a substantial portion of the harvested crop (10-20 percent) is culled and accumulates as waste at processing facilities. Many acres are not harvested each year when disease and insect damage reduces the quality of the crop below the rigorous standards of the food industry.

Production of food-quality pecans requires a high level of management, and a significant portion of current pecan acreage consists of neglected or abandoned trees. Abandoned fields typically contain a large number of young trees crossed with nearby native species or closely related hickories that produce nuts of low quality. In addition, many acres of native pecan trees are found growing wild in wet, bottomland forests along rivers.

As a result, LSU AgCenter researchers began to assess the feasibility of using nonmarketed pecans as a feedstock to supplement the U.S. biodiesel industry.

Commercial production of pecans is primarily in the southeastern United States, with Georgia accounting for as much as 40 percent of U.S. production. Between 2006 and 2008, total U.S. pecan production ranged from 119,000 to 208,000 tons (unshelled equivalent) and averaged 155,000 tons. These yields are based on utilized nuts, not the total harvested. Unfortunately, records of total harvest or total acreage planted to pecan trees are not available; therefore, it is not possible to estimate the amount of pecans available to extract oil for biodiesel.

The oil content of pecan and some closely related hickory nuts ranged from 17 percent in water hickory to 40 percent in Little Page, a commercial native pecan. On a tonnage basis, oil yields ranged from 53.3 to 128 gallons per ton of fresh nuts. Though pecan yields vary among years and regions, 1,000 to 1,500 pounds per acre is a reasonable estimate of harvested yield in the Southeast, indicating the oil yield from improved and native pecan trees ranges from 54 to 96 gallons per acre. Nut and oil yields of pecan orchards under minimal management are likely to be much lower. Also, nut and oil yields of related species and native pecans crossed with hickory are substantially less.

The fatty acid composition of pecan oil consists primarily of oleic and linoleic acids with less than 1 percent unsaturated fatty acids. This composition is similar to that of soybean oil except pecan oils sampled in this study also contain 17-34 percent of an omega-9 monounsaturated fatty acid. This mixture of fatty acids suggests pecan oils can be used to produce biodiesel capable of meeting ASTM standards, though additional tests are needed to fully characterize biodiesel derived from pecan and hickory oils.

The dollar value of pecan nuts based solely on their oil content, assuming a target price of $2 per gallon for oil, would range from $107 to $256 per ton. These estimates do not consider the costs of cracking nuts and extracting oil, nor do they consider the value of the defatted meal. Though high in protein, defatted meal has no current market as an animal feed supplement or other use.

Harvesting costs typically average $170 per acre and are likely to be higher for harvesting native pecans and water hickory in naturalized stands. These values suggest that pecans have little likelihood of serving as a viable biodiesel feedstock with the exception of processing culls, where harvesting costs are not a consideration. Assuming an average annual U.S. yield of 155,000 tons of processed pecans and culling rates of 10-20 percent, 15,500 to 31,000 tons of culls containing 1.2 to 2.5 million gallons of oil are available annually. While not a vast amount, these culls represent a disposal problem that could be used beneficially to help address the critical need for biodiesel feedstocks.

Dry shells represent about 42-60 percent of the weight of fresh nuts, and in a processing facility, shells represent a resource far larger than culls. Solvent extraction of ground shells yields about five percent oil. Processing these shells for oil may be worth consideration at a facility equipped to extract oil from culls.

While the composition of pecan oil appears to be suitable for biodiesel production, low yields and the high costs of harvesting suggest that collecting and processing pecans as a biodiesel feedstock would require a per-gallon oil cost far in excess of soy oil, even at today's elevated prices. The exception is processing culls, which are seasonally available in centralized locations. The supply of these culls is limited and unlikely to have a national impact on biodiesel production, but processing them into oil may offer an attractive and profitable alternative for disposal of these nuts at large pecan processing facilities. ■

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Photo by John Wozniak

Table 1. Oil content of pecan and some closely related hickory nuts.

Source	Kernel	Meal	Oil	Oil	Value*
	Percent of fresh weight			*gallon/ton*	*$/ton*
Water hickory	0.41	0.24	0.17	53.3	106.6
Elliott improved variety	0.49	0.12	0.36	114.7	229.4
Inglewood pecan	0.43	0.10	0.34	107.1	214.1
Little Page pecan	0.53	0.12	0.40	128.0	256.0
Pignut hybrid	0.41	0.13	0.28	89.5	179.0
Processing culls	0.35	0.10	0.25	79.8	159.5

*based on oil at $2 per gallon

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4-H'ers make ethanol during 2009 National 4-H Week

To help celebrate National 4-H Week in 2009, which was Oct. 4-10, Louisiana 4-H members joined millions of other 4-H'ers across the nation in participating in a science and technology project. They made ethanol, one of the most common biofuels in the country.

"Every parish received at least one Biofuel Blast experimental kit," said David Boldt, state 4-H science and technology coordinator. "The kit provided all of the components and instructions for conducting the experiment and is the same kit used across the country.

"Because of this year's focus on biofuels, we are going to expand the lesson and have students throughout the year make biodiesel. This biodiesel will actually be used to power AgCenter equipment," Boldt said.

Illustration by Megan Smith

To make ethanol, the students must break down the sugars in corn syrup by adding yeast. The chemical reaction will produce ethanol along with carbon dioxide. The lesson will also expose students to other possible biofuel ingredients that grow in Louisiana including sugarcane and soybeans.

"This experiment is an example of how 4-H is focusing on science, engineering and technology. 4-H activities can provide assistance to schools in these areas and improve the educational experiences for those participants," said Mark Tassin, director of the LSU AgCenter's 4-H and youth development program.

The goal of the emphasis on science, engineering and technology, also known as SET, is to produce more scientists.

"The United States is falling dangerously behind other nations in developing its future workforce of scientists, engineers, and technology experts. To ensure global competitiveness, we must act now to prepare the next generation of science, engineering, and technology leaders," according to National 4-H Web site (www.4-H.org).

In Louisiana, more than 275,000 students participate in 4-H activities each year. The youth program is administered through the LSU AgCenter and has clubs located in all 64 parishes. Nationally, approximately 6 million young people take part in 4-H.

If anyone is interested in starting a 4-H club in a school or town or becoming a volunteer leader, contact your local parish LSU AgCenter extension office or go to www.lsuagcenter.com/4h. ■ **Craig Gautreaux**