ENERGY-RELATED RESEARCH

COLLEGE OF AGRICULTURAL, CONSUMER AND ENVIRONMENTAL SCIENCES

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I L L I N O I S
From the corn fields of Illinois to the foot of a volcano in Japan, University of Illinois scientists are exploring sources of energy to provide renewable, safe, reliable, and affordable power to our homes, schools, businesses, industries, and the world.

The next research breakthrough may be discovered in a new perennial plant grown for its mammoth biomass, in the energy conversion system of a cow’s stomach, or in a soil bacterium that can only be seen under a microscope. But the possibilities are there. Renewable, more efficient energy is a goal that the College of Agricultural, Consumer and Environmental Sciences (ACES) is actively pursuing. However, it takes the dedicated, skilled, and visionary work of talented scientists to move from theory to practice.

That’s why I am proud to be part of the exciting energy-related research underway at Illinois in the College of Agricultural, Consumer and Environmental Sciences. This publication provides a glimpse of the research that is aiming to provide practical and safe solutions to the world’s energy needs for today and for the future.

Jozef Kokini
Associate Dean for Research
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ALGAE: RICH RESOURCE FOR BIOFUEL PRODUCTION

More than just scum.
Algae are a diverse family of simple plants, ranging from common pond scum to ocean seaweed. Some of these species are being considered as a promising source of raw material for future biofuels production.

Lance Schideman, a professor in the Department of Agricultural and Biological Engineering, said there are a number of reasons he believes algae to be a “credible frontrunner” among the various biomass feedstocks being researched for alternative fuels.

"Key advantages for algae include prolific growth rates and relatively high oil contents in certain species," said Schideman. "In addition, algae can help clean up water resources with excess nutrients and can be grown on lands that aren’t useful for agricultural purposes."

"Corn ethanol, soybean biodiesel, and most other dedicated energy crops would generally take prime farmland out of production for food, which is problematic when food demand outstrips supply," said Schideman. "In contrast, algae can be grown just about anywhere—in a polluted pond, in a bioreactor on top of a power plant. It can even be harvested out of the ocean."

Algae can be more productive than corn or soybeans, Schideman noted. “Right now we get about 45 to 75 gallons per acre for soy biodiesel and 300 to 500 gallons per acre for corn ethanol. Current research suggests that we could get anywhere from 1,000 to 10,000 gallons per acre for algae biodiesel. Only time will tell where we will end up on the yields of mass algal cultures for biofuels, but with gains in research and innovation over time, I think we’ll be able to improve significantly on the low-end estimates.”

Schideman said there are various options to produce biofuel from algae. “The traditional method is to extract the algae oil from the other biomass components—primarily carbohydrates and proteins—and then convert the oil to biodiesel via transesterification, which is quite similar to soy biodiesel processing. Unfortunately, the predominant methods of algae oil extraction are still relatively expensive.”

An alternative processing method is called thermochemical conversion, or TCC, a process that transforms organic compounds in a heated and pressurized enclosure to produce a biocrude oil.

“TCC gives you the option of processing the algae biomass directly, without drying it or separating out the other fractions,” Schideman said. “The oil stays as oil, and some of the proteins and other organics actually get converted to oil. It simulates the processes that went on in the earth when our petroleum reserves were formed; you’re just doing it a lot faster.

“It’s my opinion that TCC will be a very important technology in helping biofuels from algae become a reality.”

Schideman is currently involved with three projects that address significant environmental issues in conjunction with algae-based biofuel production.

One project, sponsored by the Dudley Smith Foundation, is focused on combining TCC with algae growth on livestock wastewaters to produce biofuels and reduce the environmental impacts of manure disposal.

“We also have some seed funding from the College of ACES Office of Research to investigate the feasibility of harvesting natural algae blooms efficiently,” Schideman said. “It’s a new approach to the hypoxia problem created by algae growth in the Gulf of Mexico that could yield environmental benefits much faster than other proposed hypoxia remediation measures.”

Schideman is also the advisor on a project that will address carbon sequestration through algae biodiesel production. “Carbon dioxide emissions from the power industry contribute to growing concerns about global climate change,” said Schideman. “Since carbon dioxide is a necessary component for algae growth, this project will sequester carbon dioxide from a local power plant’s exhaust gases into algae biomass that will subsequently be converted into biofuels.”

Students from the local chapters of the Water Environment Federation and Engineers Without Borders will participate in the project to demonstrate algae bioreactors that can reduce carbon dioxide emissions from the coal and natural gas stacks at the Abbott Power Plant in Champaign, Illinois. The resulting biomass will be converted into biodiesel and used to power University vehicles.

When Schideman looks to the future, he sees the production of algae biodiesel as a decades-long project.

“I think we’re within about 10 years of being able to make production economically feasible,” he said, “but do I think algae or any biofuel will replace petroleum in 10 years? No. That will require significant infrastructure and regulatory developments that will play out over 30 to 50 years.”
Obtaining long-term knowledge about a plant that has only been grown in the United States for about 12 years is difficult. That’s why two U of I scientists are going back to the source. Miscanthus x giganteus is the hybrid “child” of M. sacchariflorus and M. sinensis, species that are native to Japan.

Plant physiologist Ryan Stewart and Fabián Fernández, a specialist in soil fertility and plant nutrition, are researching these Miscanthus parent plants on plots at Hokkaido University and several other locations on the islands of Japan, including one plot at the foot of a volcano.

Stewart is studying the plants above the ground, while Fernández is looking at what’s going on in the soil. “Soils made out of volcanic activity create some challenges for a comparison study with our soils in the Midwest,” said Fernández. “But as far as the need for nutrients, that will be the same across the board for the plant; nitrogen is nitrogen.”

Fernández said he wants to be able to measure the long-term impact of Miscanthus on carbon sequestration potential and nutrient distribution in the soil. “If we have an area where Miscanthus sinensis has grown for hundreds of years, we can compare that soil to the soil in an area where it hasn’t been grown.”

Having that kind of long-term data can serve to predict what could occur in U.S. soils if Miscanthus were grown for a long period of time. “In addition, we are interested in measuring greenhouse gases such as carbon dioxide, methane, and nitrous oxide to determine the total global warming potential of these systems,” said Fernández.

Stewart is studying the plant itself. In his test plots in Japan he is evaluating agronomic traits such as growth, photosynthesis, stress resistance, and flowering time. “The hybrid plant is sterile, but the parent plants in Japan are fertile, so we’re studying the flowering cycles,” said Stewart. He explained that the flowering periods of the two Miscanthus parents are a month apart in one location, and the cycle is just the opposite in another location. But there is a part of Japan where the flowering times curiously overlap, allowing for natural crossing. “It could be climate dependent. We’re not sure,” said Stewart. “We want to see if there are more instances of natural crossing, which would make it a lot easier from a breeder’s perspective.”

At this point, all of the research is being conducted in Japan. “We haven’t brought any parent species into the U.S.,” said Stewart. “I consider this a first step. Obviously the best data will be what we gather in our own country, but in the meantime this is an opportunity for us to learn from areas in another country in which Miscanthus species have been managed for hundreds of years.”
Going to the source.
320 acres.
BIGGEST BIOFUELS CROP RESEARCH FARM IN THE NATION

On the University of Illinois South Farms, 320 acres are devoted to the largest biofuels research farm in the U.S., growing crops that could be used to produce renewable energy. Last year the farm planted Miscanthus, switchgrass, corn, and tall grass prairie species as bioenergy crops. The goal is to compare insect and disease challenges, environmental benefits, economic opportunities, and potential energy per acre of each.

Tim Mies, who directs the Energy Farm, said that research at Illinois has already shown that the giant Miscanthus grass can produce over double the biomass per acre as corn. “It does this apparently without the need for any nitrogen fertilizer, with very few other inputs, and adding significant amounts of organic matter to the soil. So Miscanthus might be a third crop for Illinois, and one particularly suited to marginal land,” Mies said.

“What having 320 acres devoted to energy crops on the Energy Farm allows us to do is to consider the benefits as well as possible downsides to these new crops and test whether native prairie plants might do just as well. "Miscanthus planting is currently a very labor-intensive operation,” Mies said. “Because it is a sterile crop and so doesn’t produce seed, the question is, how do you reproduce it at an agronomic scale?” He said that sterility has the advantage of preventing the plant from becoming invasive. “But, because there’s no seed, we have to physically go in and remove the rhizomes underground, break them apart, and then replant them into the new fields. Rather like harvesting and then planting potatoes.”

Of I researchers are working to develop machinery that can efficiently plant and harvest Miscanthus, rather than digging it up with a shovel or by hand. For it to be an effective crop, “we need to scale up the machinery to accommodate planting thousands of acres of it. Potato-handling equipment is something we’ve been looking at because it can physically go into the dirt and lift out the material,” Mies said. “However, we are moving away from being able to plant half an acre a day toward 20 acres, with the latest equipment that we are working with.”

Restored prairie as an energy crop is a relatively new concept. “Illinois used to be a prairie. If we’re going to convert possibly marginal land back to grasses, restored prairie has the potential to be a possible biomass source because it is what was naturally here before modern agriculture,” Mies said.

Crop scientist Steve Long said that ecologists have proposed this use of the land from theory and very small scale trials. “Now, for the first time, agronomists and ecologists can work together to assess the viability of this idea.”

Restored prairie is a mixture of tall grasses, grasslike plants, and flowering broadleaf plants, some of which are nitrogen fixers. Mies said that instead of management through regularly scheduled prairie burns, it would be harvested as a crop in the early winter when nutrients have been cycled back to the roots. “In theory, it makes a lot of sense to convert the land back to what it used to be, but how that might translate on an agronomic scale is yet to be seen.”

One of the challenges in growing restored prairie as a biomass crop is that it can be choked out by other more aggressive weeds. “There isn’t an herbicide you can use to control the weeds because something that would kill off the weed would also kill the plants that you want. There’s no herbicide control you can use for it,” Mies said.

The lack of uniformity of the resulting fuel may also be an issue with prairie grass.

“To process it, you want a consistent material with very little nutrient left in it,” Mies said. “A field of switchgrass is all switchgrass, whereas a field of restored prairie is a mixture of plants and grasses—the proportions of which change from acre to acre and bale to bale, a problem you wouldn’t have with switchgrass or Miscanthus.”

This inconsistency could make it very difficult to use the harvested biomass as a feedstock for processing to ethanol.

Long term, the Energy Farm will conduct research projects on many more potential biofuel crops. “We want to look at several more grasses, woody crops, some tree species that might be able to be used for biofuels, and even some sorghum varieties—not just one specific crop with a narrow focus. “We want to be a demonstration and testing farm for any possible biofuels crops that could be grown in Illinois or in this region.”

Funding for the Energy Farm is provided by the Energy Biosciences Institute and the University of Illinois.
Eco-friendly.
Ethanol plants use about four gallons of water for every gallon of ethanol they make, using the dry grind process. But investigators at the University of Illinois are trying to determine if the amount of water that is recycled during ethanol production can be increased—significantly.

“If you have a plant that’s going to produce 100 million gallons of ethanol, like the one proposed (near Urbana-Champaign), that’s about 400 million gallons of water per year. That’s not a trivial amount,” said Kent Rausch, a U of I agricultural and biological engineer involved in the project. “If we can increase the amount of recycled water from 50 to 85 percent, that will make a big difference from economic and environmental standpoints.”

In the conventional dry grind process, raw corn is finely ground and cooked; then the starch is fermented and converted into ethanol. After the ethanol has been recovered, the remaining material is called whole stillage, which contains water, protein, fat, fiber, and ash from the corn kernel and yeast. This stillage is run through a centrifuge, and about 50 percent of the water is recycled. The soluble material that remains after centrifuging is called thin stillage.

Rausch and his colleagues are planning to add membrane filtration—filtration through very small holes—to the process at this point. “We’re looking at filtering the thin stillage to improve our ability to recycle it,” said Rausch. “Impurities that inhibit yeast growth build up in the water and reduce ethanol yield; that makes the process less efficient.” Although a total recycle may not be possible, he said, “our goal is to get rid of those impurities so more water can be recycled.”

Rausch and his colleagues are also experimenting with a modified dry grind process that removes much of the protein, fiber, and fat before the fermentation process. “The thin stillage obtained from the modified dry grind process will be different,” said Rausch. “This will affect the filtration rate through the membrane, so we will test which membrane construction and pore size will work most effectively with each process.”

Vijay Singh, an agricultural and biological engineer at the U of I, and Ron Belyea, an animal scientist at the University of Missouri, are coinvestigators for the study, which is being funded by the Council on Food and Agricultural Research (C-FAR).

“Water use is important to the economic well-being of the plant even where water is plentiful,” Rausch concluded. “Reducing the demand for water in the process should reduce the environmental footprint. We want these facilities to do all they can to be good stewards in the community.”
Innovative research at the University of Illinois is changing the way ethanol is produced—and making it more economical in the process.

Vijay Singh, U of I agricultural and biological engineer, along with his colleagues from U of I and USDA Eastern Regional Center, have developed a new corn-milling process that increases the amount of ethanol produced per batch as well as the value of the co-products resulting from the process. All that, said Singh, is the key to more profitable ethanol production.

With the price of oil going up, ethanol has become more than just an environmentally friendly alternative fuel. Many experts see it as a sorely needed solution to America’s dependence on imports.

But according to Singh, the conventional process used for ethanol production has its drawbacks, such as the massive amount of one particular co-product: distillers dried grain with solubles, or DDGS. In the conventional dry grind process, raw corn is finely milled and cooked. The starch is fermented and converted into ethanol, and the three non-fermentables (germ, protein, and fiber) are carried through the process and recovered at the back end as DDGS.

One bushel of corn produces 2.65 gallons of ethanol and 15 to 17 pounds of DDGS. That’s a lot of DDGS, said Singh. Making use of all of it is a major problem. DDGS is used as livestock feed, but because of its high fiber content, it is fed mainly to ruminant animals, such as dairy and beef cattle.

Singh’s process reduces the volume of DDGS produced and improves its nutritional characteristics.

The process, called enzymatic dry grind, soaks the corn in water for a short period of time, then grinds it coarsely and incubates it with enzymes, which break down the corn kernel.

“That allows us to pull out the germ and fiber at the front end of the process, before fermentation,” said Singh. When the fiber is pulled out before fermentation, it reduces the total volume of DDGS by about 65 to 70 percent. It also reduces the amount of fiber in the DDGS and increases protein content. In fact, protein content exceeds that of even soybean meal.

“So now you’ve got a high-protein, low-fiber product that can be fed to non-ruminant animals (like poultry and swine), as well as cattle,” he added. “The problem of utilization goes away.

“When you pull this germ and fiber out, you’ve also created space in the fermentor that you can fill with more starch,” Singh said. “So you can produce more ethanol per batch.”

Another benefit of the enzymatic process is the recovery of germ and fiber, which are valuable co-products themselves, used in a variety of products, including corn germ oil and corn fiber oil.

Singh believes the enzymatic dry grind process will greatly increase the profitability of ethanol production.

“This process increases the amount of ethanol per batch, reduces the volume, and improves the quality of DDGS,” he said. “That’s pretty significant.”
Enzymes.
When a small city or town considers adding an ethanol plant or biorefinery to their community, often it’s the financial and property capital that’s counted. But what are the cultural and social effects on the community? That’s what University of Illinois professors Gale Summerfield and Stephen Gasteyer (now at Michigan State University) and graduate student Keith Taylor are analyzing in two real-life cases in Illinois.

Palestine, Illinois, is a small community with a population of about 1,300. Lincolnland Agri-Energy opened an ethanol plant there in 2004. Summerfield and Gasteyer have been comparing and contrasting the issues faced by the town and the effects of the plant with other communities where ethanol plants have been sited, including a proposal by The Andersons company for an ethanol plant in Champaign.

“We use what’s called the community capitals framework for examining the effects on community development, capacity, and resiliency as well as global linkages, not just the financial effects,” Summerfield said.

For example, water is natural capital. “Water is really important with ethanol plants, because you have to have a source nearby. What came up in the comparison study is that in some places the water source was perceived as more threatened and in other places it wasn’t,” Summerfield said.

Looking at the cultural capital has to do with the legacy of the community. “Palestine is a tiny farming community, so there is less diversity and more uniformity of heritage,” Summerfield said. It wasn’t a stretch for them to add a refinery to the community that would help farmers. In comparison, Champaign is a much bigger community, with many different kinds of cultural heritage. “Ties to the farming community are there, but there are also a lot of people who aren’t tied, so you see that in the opposition to the plant coming in.”

Summerfield studies gender issues in her research, and she noticed some striking differences there as well. “Energy isn’t an area where you typically see a lot of women. But in Palestine, the mayor is a woman, and the chair of the ethanol board of managers is a woman. Women are often more involved in alternative energy than the petroleum industry, so in the case of Palestine, the women involved brought balance, looking at how the plant would benefit the community.”

How the plants would affect the job market in the two communities was also a point of contrast. “An ethanol plant only hires about 35 people, which isn’t a lot, but for a really small community like Palestine, that’s bringing in jobs that are geared toward people with more training, which can benefit the community as a whole,” Summerfield said.

Summerfield also examined some of the differences in the political climate of the two communities and how the plant has helped Palestine financially, although she said that the excess capacity of ethanol combined with the lower (though volatile) price of petroleum meant it was not a good year for alternative energy of any kind.

Summerfield found the most remarkable differences to lie in what she calls “social capital.” This aspect has to do with networks and interactions between people. For Palestine, time will tell whether they will be able to make connections with groups throughout the state and nationally. The recession has affected the potential for entrepreneurship there. “There might have been byproducts or other businesses like local development groups who could give small loans to start-up businesses,” Summerfield said.

“Using the community capitals framework, you look at a much more systemic approach to communities rather than one little piece.”

Summerfield said that she likes to think that this methodology could help bring several capitals together to see how they can help the sustainability of communities. “I’m concerned that we’re not encouraging the building of the next generation of rusted-out infrastructure—you want to have a longer term view so these communities don’t get a couple of years of gain and then 10 years of cost.”

The next step will be more in-depth interviews in the communities.

Funding for the preliminary research was provided by the University of Illinois.
COMMUNITIES AND ECONOMIC DEVELOPMENT WHEN ETHANOL MOVES IN
The Center for Advanced BioEnergy Research (CABER) at the University of Illinois is planning to construct an integrated bioprocessing research laboratory—a state-of-the-art facility focused on the conversion of renewable feedstocks into biofuels. The facility will be a test case for eco-friendly construction techniques.

The lab is funded in part by a grant of $20 million from the State of Illinois. The facility will support multistage processing that converts soybeans, corn and other grains, lignocellulosic-based co-products, and food processing by-products into new and improved feeds, foods, energy sources, industrial feedstocks, and chemicals.

The multidisciplinary facility will focus on the chemical, physical, and biological conversion of renewable feedstocks into biofuels and will provide opportunities for developing new production processes for biofuels, industrial chemicals, and nutraceuticals.

“The time is ripe for development of a unique bioprocessing facility, since the chemical industry is expected to transition from petroleum-based processes to bio-based technology,” said CABER director Hans Blaschek.

“The new facility will allow translational research to be carried out from the laboratory bench to the pilot-scale level in anticipation of commercialization.”
More sugar.

Stephen Moose with researcher FredBelow
University of Illinois plant geneticist Stephen Moose has developed a corn plant with enormous potential for biomass, literally. It yields corn that would make good silage, Moose said, due to a greater number of leaves and larger stalk, which could also make it a good energy crop.

The gene, known as Glossy 15, was originally described for its role in giving corn seedlings a waxy coating that acts like a sunscreen for the young plant. Without Glossy 15, seedling leaves instead appear shiny and glossy in sunlight. Further studies have shown that the main function of Glossy 15 is to slow shoot maturation. Moose wondered about the result if the action of the gene were turned up.

“T<br>he ears of corn have fewer seeds compared to the normal corn plant and could be a good feed for livestock. “Although there is less grain, there is more sugar in the stalks, so we know the animal can eat it and will probably like it.” This type of corn plant may fit the grass-fed beef standard, Moose said.

“The first time I did this,” said Moose, “I thought, Well, maybe the seeds just didn’t get pollinated very well. So I hand-pollinated these ears to make sure. I found that just like the shoot, seed development is also slower, and seeds just don’t make it all the way to the end with plump kernels.”

Moose explained that the energy to make the seed goes instead into the stalk and leaves. “We had been working with this gene for a while. We thought there would be more wax on the leaves, and there was. But we also got this other benefit, that it’s a lot bigger.”

Moose tested his hypothesis with other corn lines and the effect was the same. “We essentially can make any corn variety bigger with this gene. And it can be done in one cross, and we know exactly which gene does it.”

He noted that putting in too much of the Glossy 15 gene slows the growth too much, and frost kills the plant before it can mature.

One advantage to growing sugar corn rather than switchgrass or Miscanthus for biomass is that sugar corn is an annual. Moose said that if it would attract a pest or develop a disease, farmers could rotate a different crop the next year.

Moose said that sugar corn might make a good transition crop.

“We think it might take off as a livestock feed, because it’s immediate,” Moose said. “This would be most useful for on-farm feeding. So a farmer could grow this and use the corn as feed and sell the stalks and sugar.”

To become commercialized, the sugar corn plant would need government approval, but Moose said that Glossy 15 is about as safe a gene as you can get. “It’s a gene that’s already in the corn—all we did was to put an extra copy in that ramps it up.”

Findings from this research were originally published in the Proceedings of the National Academy of Sciences of the United States of America in 2005.
PREDICTION MODEL SHOWS LAND’S POTENTIAL FOR FOOD AND FUEL

Madhu Khanna
Economic viability of non-corn biofuels depends on yields per acre and the cost of land, said a University of Illinois agricultural economist.

And, added Madhu Khanna, a professor in the U of I Department of Agricultural and Consumer Economics, these biofuel crops require relatively little nitrogen use and reduce total greenhouse gas emissions by more than half. However, the costs of non-corn biofuels from corn stover, Miscanthus, and switchgrass are considerably higher than those of corn ethanol. Biofuel mandates imposed by the Energy Independence and Security Act of 2007 require 21 billion gallons of non-corn ethanol by 2022 and could result in high ethanol costs in the absence of technological breakthroughs in the production of cellulosic biofuels.

Khanna and fellow U of I professor Hayri Onal reached these conclusions in their study, “Meeting Biofuels Targets: Implications for Land Use, Greenhouse Gas Emissions and Nitrogen Use in Illinois.” The study is being published in the Handbook of Bioenergy Economics and Policy being coedited by Khanna and published by Springer.

Together with graduate student Xiaoguang Chen, Khanna and Onal developed a dynamic microeconomic land use model to identify the likely allocation of cropland for traditional row crops and perennial grasses in Illinois if the state were to produce 20 percent of the U.S. Renewable Fuels Standard between 2007 and 2022. Illinois currently produces about 20 percent of U.S. ethanol production.

“We simulated the profit-maximizing land use decisions in Illinois between 2007 and 2022 if the state were to maintain its present share in the national biofuel production under several different assumptions about the costs of production of various feedstocks such as Miscanthus, switchgrass, and corn stover,” Khanna explained.

“Imposing biofuel targets has three types of effects on land uses,” she said. “First and foremost, it increases the demand for cropland, which in turn increases the cropland brought into production relative to that with no biofuels.

“Second, the mandate leads to a conversion of land from food crops to biofuel crops. Finally, the biofuel targets and resulting demand for corn lead to a significant change in the tillage and rotation choices for crop production.”

The study estimates that with biofuel targets, cropland use in Illinois would increase by about 5 percent in 2022.

“The percentage of land under corn increases from 47 percent to 53 to 55 percent,” she said. “We also found a decrease in the percentage of land under soybeans—from 45 to 29 percent. Wheat acreage would see a 15 percent reduction, and pasture land would decrease by 44 percent.

“Of total corn produced, over half would be for ethanol if Illinois produces 20 percent of the biofuel mandate in 2022.”

The model also showed 14 percent of cropland diverted to produce Miscanthus.

“The diversion of land to biofuel production affects the prices of both corn and soybeans because of the reduced availability of these commodities for food and feed uses,” Khanna said.
Best bioreactor.
Breaking down the cellulose of plant materials into sugar is the critical step in producing fuel from plant-based, renewable energy sources, and the most efficient path for achieving this runs through a cow’s stomach.

“The best microbes for doing this are in the cow’s stomach,” explained Isaac Cann, a professor in the Department of Animal Sciences who is engaged in a major research project on the topic. “For millions of years, cows have been evolving to do this, and today the cow’s stomach is the best bioreactor in nature for plant cell wall hydrolysis.”

Microbes, he explained, break down the plant material, converting it into volatile fatty acids, which in turn become an energy source for the cow.

Cann’s research is focusing on how those enzymes work and how they might be reproduced in a large-scale project. The immediate goal is finding a way to convert corn waste products into fuel, thereby saving the kernels for human and livestock feed purposes while creating new markets for what has been waste.

“Thinking things like corn cobs, leaves, etc.,” he said. “In addition, we are interested in using the giant grass Miscanthus.”

Demand for biofuel is driving up prices for corn and soybeans. At the same time, it has triggered a food-versus-fuels debate. Finding ways to utilize plant waste products, however, bypasses this debate by potentially creating new markets and uses for materials now tossed aside.

Cann quickly admitted that the idea of converting plant waste to fuel is nothing new.

“People have tried this before, but the price of gasoline was too cheap to make it economically feasible,” he said. “Now there is an influx of money from the government and producers to find ways to do this and, of course, the price of gas is much higher.

Cann’s work is funded as part of a massive $500 million project at the University of Illinois; the University of California, Berkeley; and the Lawrence Berkeley National Laboratory, which is backed by BP.

Cann’s path to this project is an interesting one. Originally from Ghana, Cann did graduate work in Japan before taking a three-year postdoctoral position in the Department of Animal Sciences. He now has appointments in the University of Illinois Energy Bioscience Institute and the Department of Microbiology.

From his experience in Ghana, Cann knows the importance of corn as a food product for humans and livestock, and he recognizes the tremendous economic potential of creating fuel from waste products.

“Something like this is very important for our farmers here in the United States and will have an impact on their lives and enterprises,” he said. “We’d like to come up with something that will increase their profits.”
Research at the University of Illinois is one step closer to opening up a billion-dollar market to the hog industry and reducing U.S. dependence on crude oil imports. U of I scientists have teamed with industry partners to design a pilot plant for a large commercial livestock farm that will convert swine manure to crude oil.

The pilot plant is based on research led by Yuanhui Zhang, an agricultural and biological engineer at the U of I. Zhang and colleagues developed a system using thermochemical conversion (TCC) to transform organic compounds, like swine manure, in a heated and pressurized enclosure to produce oil and gas.

"The process we developed is different from most conventional TCC processes," said Zhang. "There is no need for the addition of a catalyst, and our process does not require pre-drying of the manure."

The initial stage of Zhang’s research led to the development of a batch TCC reactor.

"With a batch reactor, you ‘cook’ one batch, empty it, then cook another batch, empty it," said Zhang. "Now we have a continuous reactor, which means continuous pumping of feed stock and continuous output. The development of a continuous reactor brings the technology one step closer to a TCC pilot plant."

Zhang’s team has achieved as high as 70 percent conversion of swine manure volatile solids to oil. At that level of efficiency, the manure excreted by one pig during the production cycle could produce up to 15 gallons of crude oil and add a profit of $10 per pig. In the U.S. industry alone, producing 100 million hogs a year, that adds up to a billion dollars.

The National Pork Board and Illinois Pork Producers Association have helped fund the project. Jim Kaitschuk, executive director of IPPA, said, “We’re very supportive of this research. We see a number of advantages to producing crude oil from swine manure, which includes adding value to manure products.”

Steps are now being taken to build a pilot plant that will help determine if the TCC process can live up to the projected numbers. Les Christianson, a professor emeritus in agricultural and biological engineering at U of I and the industry liaison for Zhang’s team, is optimistic about the potential for the manure-to-oil process.

“We believe that this can be economically feasible on a commercial scale,” he said. “The first plant won’t be the final design, but it will help us figure out what the right design is. Every technology goes through a learning curve, when you improve quality and reduce costs.”

Zhang’s team has expanded his research to determine if other types of livestock manure, human waste, food processing waste, and algae can be used as feedstock for the TCC process.

“Billions of dollars are spent on waste transportation and treatment, and regulations continue to become more stringent and cost-intensive to satisfy our desire for a clean environment,” said Zhang. “Meanwhile, we have a growing need for biofuels that would reduce our dependence on foreign oil and the world’s finite supply of crude petroleum.

“It is vitally important that we develop innovative solutions that can address both those problems,” he concluded.
Pig performance.
Bacteria and butanol.
As a chemical for industrial processes, butanol is used in everything from brake fluid to paint thinners to plastics. According to a University of Illinois researcher, butanol made from plant material could displace butanol made from petroleum, just not at the fuel pump.

“Yes, you can drive your car around with 100 percent butanol, but butanol is much more valuable—about three times more valuable—as a chemical than as a liquid fuel,” said Hans Blaschek, microbiologist in the Department of Food Science and Human Nutrition at the University of Illinois.

Blaschek said that butanol has multiple attributes that would make it a good candidate for liquid fuel—it burns cleaner and has higher energy density than ethanol, but it’s currently more expensive.

“It would displace petroleum, and that’s huge—clearly—it could be used as a liquid fuel, but right now it’s still too expensive to use that way. Right now it follows the price of propylene,” Blaschek said.

Blaschek has been studying microorganisms that are used in fermentation processes for over 25 years. About 10 years ago, his lab at Illinois had a breakthrough with the development of a mutant strain of a soil bacterium called Clostridium beijerinckii that produces higher concentrations of butanol when added to a vat of plant by-product.

Simply put, what yeast is to the process that creates ethanol, Clostridium beijerinckii is to the process that results in butanol.

As Blaschek explained, “One of the beauties of Clostridium is that unlike yeast that can only use six carbon sugars, this organism can use five or six carbon sugars, so you’re not limited. You can use distillers grains, biomass, pretty much anything that can be deconstructed to sugars and can be fermented. Clostridium eats both, and it does it naturally. You don’t have to engineer the organism like people have been doing for the last 20 years with yeast trying to get it to use five carbon sugars.”

Because the mutant strain produces higher concentrations of butanol, it’s the basis for TetraVita BioSciences, a local company that licensed the patented strain from the University of Illinois and is scaling up to use the overproductive strain on a large scale—the size of an ethanol plant.

“When we did the original study 10 years ago that resulted in the mutant strain, we didn’t do it in a nice, careful way using sophisticated molecular biology. We did it using brute force, and it worked. However, the problem with that approach is that you don’t really know what genetic alterations caused the enhanced production.”

Blaschek’s most recent research on Clostridium was at the genetic level. “In 2004 we put a request in to the Department of Energy to sequence the parent strain,” he said.

“After we had access to the sequencing information, we were able to do the first global evaluation of the two strains—the one that overproduces butanol together with the parent strain—to see what genetic alterations were responsible for this attribute.”

In the lab, the two strains went through fermentation separately, with samples taken during the course of the fermentation. The RNA was isolated, and microarray technology was used to tell how much RNA was present at a given time in the fermentation. The assumption is that if there is more RNA, there’s more protein. This was done for a series of 500 different genes. The analysis was used to look at the wild type alongside the mutant.

Blaschek found that the amount of RNA being produced for certain enzymes involved in butanol production was much greater in the mutant strain than in the wild type. There was also a difference in the ability of the mutant to make spores.

Blaschek said that the organism doesn’t make any butanol until later in the fermentation process. So it has been thought that if you can prevent the organism from going into the next physiological state, which is sporulation, you can keep it more or less producing butanol.

“The next step is to take that knowledge and produce a second-generation strain, not with the brute force approach that I used earlier, but actually going in and very specifically making those genetic alterations in a targeted sort of way. You would take the wild strain and mutate the gene for the characteristic that you’re interested in. And now that we have the sequence, we actually know where those genes are,” he said.

The research comparing the two strains was published in the January 2009 issue of Applied and Environmental Microbiology.
Fat’s in the fire.
We all know that saturated fats are bad for humans. But research at the University of Illinois is showing that what's bad for humans might be good for biofuels.

“Biofuels are made from a range of different vegetables and animal fats,” said Alan Hansen, a professor in agricultural and biological engineering at the U of I. “And one of the properties of a biofuel that determines how efficiently an engine runs is its fatty acid composition.”

As it turns out, palm oil, which may be regarded as unhealthy for humans because of its abundance of saturated fatty acids, makes a good biofuel. But polyunsaturates, which are healthier for humans, “are not good for engines because they lower the cetane number, or the ignition quality, of the fuel dramatically,” Hansen said.

“So it would seem that what’s good for food is not necessarily good for fuel.” Hansen noted that palm oil for biofuel doesn’t work well in the Midwest due to temperatures below 60 degrees F.

Hansen is investigating the properties of different biofuels, he said, “because they are used in combustion modeling exercises and experiments, and we want to be able to model the combustion of these different biofuels as accurately as possible.”

Hansen is working with researchers from the Department of Mechanical Science and Engineering to study a variety of issues related to the automotive combustion of biofuels. The group recently received a grant from the U.S. Department of Energy to fund the new Graduate Automotive Technology Education (GATE) Center of Excellence on Advanced Automotive Bio-fuel Combustion Engines.

Chia-Fon Lee, a professor in mechanical science and engineering, is the center’s director. Lee and three colleagues in the department, Professor Dimitrios Kyritsis, Professor Emeritus Robert White, and Robert Coverdill, senior research engineer, are all working on developing engines that will burn biofuel more efficiently.

“Even though you can see through it, said Lee, everything happens so fast that laser equipment is needed to take images that track the combustion process.

“Even though you can see how much remains as liquid, how much turns into vapor, and how much it penetrates into the combustion chamber—all characteristics that are important to determine the combustion,” said Lee.

Funding from the Department of Energy will allow Lee and Hansen to work with The GATE Center for the next five years, and Lee says there is a possibility of an additional five years of funding.

“The GATE project has an educational component that we didn’t have in the past,” Lee said. “Now we are able to train talented graduate students in both mechanical and agricultural/biological issues related to automotive biofuel combustion. We are also conducting a GATE seminar series that presents information you can’t find in textbooks. Even the professors get a lot out of it.”

Hansen concluded, “With all the interest in biofuels at the moment, it’s a great opportunity to see how we can take advantage of the new technologies to get an engine to run on biofuel more efficiently.”
In the summer of 2008, gas prices skyrocketed and both U.S. presidential candidates promoted renewable, domestic sources of fuel as the answer to our environmental and political problems. These were two of the factors that motivated John Buns to pursue a professional science master’s degree in bioenergy at the University of Illinois.

The degree program is offered through the Center for Advanced BioEnergy Research (CABER) in the College of ACES. Buns selected Illinois for a variety of reasons. “In a long list of ‘biotechnology’ programs ‘bioenergy’ visibly stood out,” he said. “I realized that there would be plenty of government incentives to start bioenergy-related companies in the near future and that the decreasing global supply of oil and coal would create a demand which these new companies could meet.”

Buns spent his last semester as a Northern Arizona University undergraduate in Limerick, Ireland, taking advanced biotechnology courses. “I was looking forward to entering the biotech industry, but when I came home gas was $4 per gallon and the economy was fading. “I decided I wanted to further my education and liked the idea of a program that combined business with science, law, and regulation. I have always felt that my niche was in combining multiple disciplines rather than being an expert in one, so a professional science master’s degree was exactly what I was looking for.”

U of I’s large size and outstanding reputation appealed to Buns. “I wanted to work alongside motivated students looking to make a significant impact in the renewable energy industry and knew I’d find that at Illinois.

“I also had a personal interest to attend U of I. My parents, grandparents, and cousins went here, so being able to get a taste of what they experienced was very enticing.”

CABER director Hans Blaschek said that the professional science master’s program in bioenergy builds bridges between science and business to meet the state’s and the country’s needs for sustainable energy.

“There is a growing demand for a well-educated scientific–technical workforce in bioenergy and related biosciences,” Blaschek said. “Because this program includes practical activities and internships, it will result in a pool of skilled scientists, managers, engineers, economists, and technicians who will be able to apply the advanced and innovative methods of energy production.”
Preparing professionals.
In the race to achieve independence from foreign oil, Brazil has crossed the finish line. Cars in Brazil already run on 100 percent ethanol made from sugar cane. University of Illinois agricultural and biological engineer Vijay Singh is one of many U.S. researchers who want to learn from Brazil’s successes with sugar cane and collaborate to develop new, more efficient and affordable energy resources.

“The United States is number one in ethanol production. Brazil is number two. We make it from corn. They make it from sugar cane,” said Singh. “Most of their cars are flex fuel, so they can run on 100 percent ethanol or a blend of gasoline and ethanol.”

Singh said Brazil adopted a fuel-alcohol program in the 1970s, so they have a head start in the race. “Ethanol made up more than 40 percent of the fuel used by gasoline-powered vehicles in Brazil.”

Singh is a member of an advisory board created under the auspices of the U.S. State Department through the Fulbright Commission. The goal of the advisory board is to guide a U.S.–Brazil biofuels network made up of researchers and institutions in the two countries so that research and information can be shared.

“The first thing the board decided to do was to put together a two-week biofuels short course to be held at the University of Sao Paolo in Brazil in August 2009,” Singh said. “We selected 15 graduate students from the U.S. and 15 from Brazil to take the course.”

Experts from Brazil and the U.S., including Singh, presented their research in the areas of feedstocks, biodiesel, alcohol fuels, hydrocarbons and synthetics, hydrogen, co-products, engines and lubricants, life cycle analysis, and sustainability. The graduate students selected were already working in biofuels research, so they presented their work during the short course as well.

The research I am doing is on corn-to-ethanol production,” Khullar said. “I didn’t know much about the sugar cane-to-ethanol processes. I got to see a sugar cane field and the harvester in action. It was good to see how Brazil is producing ethanol.”

Singh said that the advisory board’s next task will be to organize a similar course in the U.S. within the next year or two.
INTERNATIONAL NETWORKING ADVANCES BIOFUELS SCIENCE IN THE U.S.
On the move.
Many processes must occur between the time a plant captures the sun’s energy in a field and the point at which that energy is dispensed as fuel at the pump.

For energy crops such as Miscanthus or switchgrass, handling and processing details of the journey may be passing through uncharted territory. “There’s not as much information on energy crops as we have on corn and soybeans and wheat and cotton. So we have to build on those past successes and learn,” said University of Illinois agricultural engineer K.C. Ting.

Ting is leading a team of Illinois researchers in a program funded by the energy firm BP in the Energy Biosciences Institute (EBI)—a partnership between the University of California, Berkeley; the Lawrence Berkeley National Laboratory; and the University of Illinois. The program is called Engineering Solutions for Biomass Feedstock Production.

“We are studying the issues and logistics involved in getting biomass from field production to the gate of the biorefinery. When the truck delivers the biomass to the refinery, that’s when our job as agricultural engineers ends,” Ting said.

The program breaks the journey into five tasks—pre-harvest crop monitoring, harvesting, transportation, storage, and overall analysis of information.

In the pre-harvest crop monitoring, we look at how precision agriculture—remote sensing—can be used to help growers understand how to manage these new crops,” Ting said.

Researchers at the University of Illinois use a variety of techniques for pre-harvest crop monitoring. A tower over a hundred feet high with a multi-spectral camera watches four nine-acre plots to study the health of the crop, a small unmanned helicopter can fly over crops to acquire images, and a cube-shaped frame with sensors moves slowly across the crops.

“Using these precision agriculture methods, we can help growers monitor crop growth, detect problem areas, and suggest what they need to do,” Ting said. He added that even harvesting has several steps. The crop must be gathered, collected, loaded, and unloaded many times from the field to the biorefinery.

“Sometimes the harvest window is small, but biorefineries need a year-long supply of constant high-quantity material. We have to find ways to keep it for a whole year in storage,” Ting said.

Like passing a baton in a foot race, Ting explained, there is need for an interface between the “runners” in the energy crop value chain. The program is examining the interfaces that occur along the way—gathering data that will help find solutions and improve the overall process.

“You can have the best harvesting, storage, and transportation, but how do you link them? Global optimization is as important as local optimization. Our program looks at the whole system.”

Ting used the analogy of constructing a building. “You have lighting, you have air conditioning, you have carpeting. Someone has to come up with an overall blueprint and then resolve the differences. And to enable interfaces to happen seamlessly, you need to identify the information you need. Without information, no one can do anything.

Certainly we don’t want to recreate the wheel. There are already established methodologies and science in handling other kinds of biomass, mostly grains and cottons,” he said. “What we are doing is using the same methodology and modifying it to conduct new experiments on energy crops.”

Ting said that technologically, it’s all doable today. “But it’s very expensive and non-optimal. The challenge is how to do it with the least cost, labor, energy consumption, and greenhouse gases while delivering the highest-quality biomass.”

Ting explained that programs such as the Feedstock Production effort differ from typical research projects, because the programs involve thematic research on a large scale for an extended duration. “When this kind of important theme is funded, it’s expected that it would take 10 years to complete,” Ting said. “It’s our job to continue to contribute and keep it relevant.”
College of Agricultural, Consumer and Environmental Sciences

Whether it’s developing improved crop varieties, creating robotic components for more efficient weed control in fields, or developing the next breakthrough in bioenergy, the College of Agricultural, Consumer and Environmental Sciences at the University of Illinois is all about providing solutions for the challenges that face the citizens, communities, and businesses of Illinois.

...Real Science

> Creating progressive food and agricultural systems > Fostering family and community resiliency > Accelerating advances in food, nutrition, and health > Innovating in bioscience—processes, products, environment, and energy

...Real Solutions

> Providing first-class discovery research purposefully translated into practice > Preparing globally competitive undergraduate, graduate, and mid-career students > Informing sound decision-making to assist policy makers, citizens, and leaders locally and around the world

Center for Advanced BioEnergy Research

The Center for Advanced BioEnergy Research (CABER) works closely with the nine University of Illinois colleges, multiple disciplinary and professional units, and faculty and students to provide a facilitative structure for campus outreach, teaching and research in areas related to bioenergy systems. CABER facilitates the development of cross-disciplinary research and development, education and outreach programs that promote the greater and more efficient use of bio-renewable resources and support the emergence of advanced bio-fuels and chemicals. CABER focuses on sustainable bioenergy systems, including plant, microbial, downstream processing, and economics and policy issues as they relate to bio-based products.

Energy Bioscience Institute

The Energy Biosciences Institute (EBI) harnesses advanced knowledge in biology, the physical sciences, engineering, and environmental and social sciences to devise solutions to global energy challenges and reduce the impact of fossil fuels on global warming. The world’s first research institution solely dedicated to the new field of energy bioscience is initially focusing on the development of next-generation biofuels, but will also look into various applications of biology to the energy sector.

EBI’s multidisciplinary research teams explore total-system solutions to global energy problems that include the sustainable production of cellulosic biofuels, enhanced biological carbon sequestration, bioprocessing of fossil fuels, biologically enhanced petroleum recovery, and the social and economic impacts of transitioning to sustainable energy.

EBI is a collaboration between the University of Illinois; the University of California, Berkeley; the Lawrence Berkeley National Laboratory; and BP, which will support the Institute with a 10-year $500-million grant. The EBI hosts approximately 25 research teams, housed at the University of Illinois and at the University of California, Berkeley.