FIELD WORK University of São Paulo graduate student Vinicius Sellani (left) takes a closer look at sugarcane with ACS's Bradley Miller.

STEVE RITTER/C&EN

BIOFUEL BONANZA

Brazil has become **A MODEL AND AN ALLY** for the U.S. in the pursuit of sustainable bioethanol, biodiesel, and bioelectricity

STEPHEN K. RITTER, C&EN WASHINGTON

THIRTY YEARS AGO in Brazil, a group of visionaries saw the potential of bioethanol made from sugarcane as a transportation fuel and created a national program promoting its use. Fast-forward to a month ago, when a group of U.S. and Brazilian chemists pulled up to the front gate of one of the more than 300 bioethanol plants in Brazil. What immediately grabbed the visitors' attention were the truckloads of hand-cut sugarcane rolling in from the fields. As they toured the facility, the visitors watched in awe as the sugarcane was transformed into sugar, bioethanol, and electricity—the process left nothing for waste.

Today in Brazil, another group of visionaries sees similar potential for the combination of bioethanol and biodiesel. In actuality, conversion of sugars and fats and oils to bioethanol, biodiesel, and value-added chemicals and materials already is helping to extend fossil fuel supplies and is starting to change the global economy. And next-generation technologies for converting cellulosic biomass to fuels and chemicals are expected to ramp up and add to the mix in the coming 30 years.

These developments make it an exciting time for scientists, chemical companies, entrepreneurs, and investors (C&EN, Nov. 20, 2006, page 30). But it's also a time for caution. Piecemeal development of biofuel technologies without regard to regional and global sustainability could lead to problems in food production, environmental degradation, trade imbalances, and social and economic failures. What's needed is an international effort that helps promote biofuel development so that all countries can participate equitably in a global energy marketplace. That's the new vision.

As one starting point, scientists and policymakers from Brazil and the U.S.—the world leaders in biofuel research and development—participated in a historic symposium in Águas de Lindóia, Brazil, on May 30–31 to create sustainable research collaborations for improving biomass conversion. A report from that meeting is expected to take shape over the next few months and will be used to inform funding agencies and policymakers in both countries on future needs in biofuels R&D. In a nutshell, Brazil has much to offer the U.S. as an experienced partner in bioethanol and biodiesel production, while the U.S. has committed to developing technologies for converting cellulosic plant material into fuels and chemicals, which could aid Brazil.

The Brazilian-U.S. effort is a collaboration between the Brazilian Chemical Society (Sociedade Brasileira de Química, or SBQ), the American Chemical Society, and the Brazilian Agricultural Research Corp. (Embrapa). Bradley D. Miller of ACS's Office of International Activities worked with SBQ's immediate past-president, Paulo C. Vieira of the Federal University of São Carlos, and Embrapa's Pedro A. Arraes to orga-

nize the venture. Miller received a National Science Foundation Discovery Corps Fellowship to support the partnership.

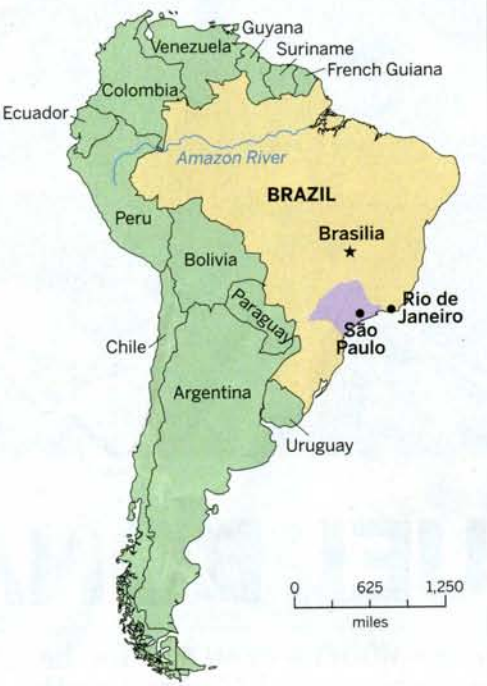
"The idea for the project grew out of the interest of the ACS Committee on International Activities in advancing chemical sciences in Latin America and a subsequent 2001 ACS/NSF delegation visit to Brazil to improve bilateral cooperation," Miller said. "There is considerable value and mutual benefit in combining U.S. and Brazilian expertise and knowledge bases in plant-derived biomass as a source for alternative fuel and other products leading to energy independence and pollution reduction."

Brazil and the U.S. each have multiyear plans for advancing biobased fuels and chemicals, Miller pointed out. The emphasis for the SBQ-ACS effort "is on identifying where there are gaps in knowledge and where we complement each other," Miller said. "We need a common road map for where and how the U.S. and Brazil can collaborate in bioconversion chemistry."

IN MARCH, after two meetings between Brazilian President Luiz Inácio Lula da Silva and U.S. President George W. Bush, the two countries signed a memorandum of understanding for establishing an energy partnership to encourage bioethanol and biodiesel use throughout North and South America. Brazil already had been quietly forging renewable fuels development agreements with a number of countries, most recently Chile, Jamaica, and Indonesia. In February, the U.S. and Brazil joined India, China, South Africa, and the European Union in forming the International Biofuels Forum. The group's goal is to ensure that conditions are favorable for bioethanol and biodiesel to become global commodities.

The Brazil-U.S. accord seemed at first to trump Miller's efforts. But he views the two approaches as complementary. At the top level, Brazil and the U.S. will be looking at the technologies in general, while SBQ and ACS will be looking at the basic science and forging partnerships for it to move forward, Miller noted.

The agreement between the two nations "is a perfect entrée into the type of bilateral science and technology cooperation that will come out of this symposium," Gale A. Buchanan, the U.S. Department of Agriculture's undersecretary for research, education, and economics, told C&EN.



BIOFUEL COUNTRY Roughly the size of the contiguous 48 U.S. states, Brazil has become a world leader in bioethanol and biodiesel, most of which is currently produced in the state of São Paulo (purple) in the south.

During a plenary address, Buchanan emphasized that "Brazil's bioethanol program is a model for the world." The opportunity for the U.S. and Brazil to work together "is very exciting," he said.

Buchanan, trained as an agronomist, also commented on the importance of chemistry in driving paradigm shifts in agriculture. Chemical fertilizers, mechanization, pesticides, and biotechnology "have all had lasting impacts on society," he said. The new paradigm of biobased products "will be more dramatic and have a greater impact on the people of this world than any of the other changes in agriculture during the past 150 years," Buchanan added. "The collaboration between our two great agricultural nations will be a benefit to everyone."

To set the tone for the symposium, Miller and Vieira put together a contingent of U.S. and Brazilian scientists that toured university, government, and industrial biofuel research labs and production sites—including the aforementioned bioethanol refinery—in the agricultural state of São Paulo during the week leading up to the meeting (visit cenbrazil.wordpress.com to view a blog highlighting the tour). The tour provided the U.S. scientists an opportunity to observe Brazil's biofuel infrastructure and begin to establish research relationships.

The most striking achievement of Brazil's biofuels industry, as the U.S. contingent witnessed, is the integrated approach for future growth being played out by scientists, government officials, business leaders, lawyers, and educators.

For example, biologists are using selective breeding and genetic engineering to prepare plant varieties that produce greater amounts of sugar or oil. This approach also is helping expand the growth range of valuable crops such as sugarcane and soybeans and is helping adapt some of Brazil's many native species of plants for biofuel production.

Soil scientists are conducting research to ensure that the country's increase in agricultural production doesn't destroy the fragile soil ecology. The reddish soil of São Paulo in southern Brazil is ideal for growing crops, but the high mineral content needs to be balanced with organic carbon by returning plant residues to the soil. Sugarcane is rotated every few years with leguminous plants, such as peanuts, which add nitrogen to the soil and can be used to make biodiesel. Agricultural scientists also are planning ahead for precipitation and temperature shifts stemming from global warming that could alter production.

Brazilians also have recognized that no one biofuel or any single crop will be sufficient to support future economic growth. Combination bioethanol-biodiesel refiner-

"Unfortunately, in the U.S., the corn fermentation route to produce ethanol is nowhere near as efficient as sugarcane fermentation. I wish we could grow sugarcane in the Midwest."

ies that also produce value-added chemicals are now being built. Even the companies that build the machinery, chemical reactors, distillation columns, and electricity generators that go into these factories are considered important pieces of the biofuels puzzle.

One of Brazil's new-age visionaries is Miguel J. Dabdoub, a chemistry professor at the University of São Paulo, Ribeirão Prêto. Dabdoub leads the Laboratory for Clean Technologies Development (LADETEL), which is investigating refinery operations to develop greener petroleum and biofuel production processes. Some students in the group are working on heterogeneous transition-metal catalysts and immobilized lipase enzymes for more efficient, faster, and lower-cost transformation of oils and ethanol into biodiesel. Other work at the lab includes developing and testing new biodiesel blends for both fuel and environmental performance.

Dabdoub seemingly has his hand in all aspects of Brazil's biofuels industry. He is frequently meeting with local and national businessmen, academics, and elected officials to make sure they understand the value of biodiesel and why it's important for Brazil, South America, and the world, he pointed out.

"The research is important, but we also have to think a lot about strategic, economic, social, and political issues," Dabdoub said. "I'm trying to build a concept where the research helps create partnerships with businesses, businesses create demand, and the demand creates a market. The most important word in our work is 'partnership.'"

Dabdoub is partial to diesel because it's a more efficient fuel than gasoline or ethanol and it provides the higher engine torque needed to power trucks, tractors, and trains.

"The world needs diesel," Dabdoub emphasized repeatedly. But it's not enough to simply make biodiesel, fill up your car, and start driving, he added. The fuel needs to be environmentally friendly as well. To achieve this goal, scientists need to first understand how the pollution created by burning biofuels differs from that created by petroleum-based fuels. Then those emissions must be minimized.

IN 2003, the charismatic Dabdoub met in Paris with executives from French carmaker PSA Peugeot Citroën to share his biodiesel ideas. He came away from that meeting having convinced the company to support his research. LADETEL now has a fleet of six cars and vans supplied by the company. As part of the agreement, the researchers receive extra engines to use for studying the effects of burning various diesel-biodiesel blends.

Every 20,000 km (about 12,400 miles), the cars are given thorough emissions tests, which are carried out in conjunction with colleagues at Brazil's Federal University of Paraná. The environmental benefit of using biodiesel over petroleum-based diesel or gasoline is emissions reduction of carbon dioxide, carbon monoxide, particulates, and polyaromatic hydrocarbons without sacrificing vehicle performance, he noted. Emissions of nitrogen oxides remain similar to other fuels.

STEVE RITTER/C&EN

FUEL TALK Vieira (from left), Buchanan, and Brazilian Chemical Society President Antonio S. Mangrich discuss potential avenues for joint Brazil-U.S. biofuels research.

At the request of the tour organizers, Dabdoub and members of his group used the fleet of highly visible cars covered with sponsor decals to shuttle the U.S.-Brazil delegation hundreds of kilometers around the state of São Paulo. During the tour, Dabdoub was running the test cars on a blend of 70% petroleum-derived diesel and 30% biodiesel, a combination designated B30. The biodiesel was made from 75% soybean oil and 25% castor oil.

It was from the windows of the LADETEL cars that the tour group first caught sight of

the sugarcane-laden trucks entering the sugar refinery and ethanol distillery. The facility, owned by the company Santa Elisa, is located near Ribeirão Prêto, a city of about 500,000 people some 200 miles west of São Paulo that lies at the heart of the world's largest bioethanol-producing region. The area is home to 26 of the 128 bioethanol plants in the state of São Paulo, which produces about 70% of Brazil's ethanol. This Santa Elisa plant, an average-sized facility by Brazilian standards, processes 6 million metric tons of sugarcane per year.

As the plant tour unfolded, a team of Santa Elisa engineers pointed out key features of the sugar- and bioethanol-production processes. The naked sugarcane stripped of its leaves is unloaded from the trucks and washed to remove residual soil, which is collected and returned to the fields. Even the treated process water from the plant, which contains valuable nutrients, is used to irrigate local sugarcane fields.

A series of five steam-powered crushers spread over an area the size of a football field noisily squeezes and shreds the cane to wring out all the juice. To make sugar, the greenish cane juice is pumped into large tanks where it's filtered and condensed. The syrup is then crystallized and centrifuged to remove excess water, leaving behind pure white granular sugar that the entourage was able to sample while it was still warm. The Santa Elisa plant produces 475,000 metric tons of sugar per year, which leaves the plant in 1-metric-ton sacks.

To make ethanol, a stream of cane juice from the crushers is diluted to a 20% sugar solution and pumped into large fermentation vats. Over 8 hours, yeasts ferment the sugar to a 6 to 10% ethanol soup. The yeasts are removed and either recycled to ferment more sugar or dried and sold as animal feed. The ethanol is then distilled and dehydrated in stages to greater than 99% purity, denatured, loaded into tanker trucks, and delivered to fuel distributors.

The Santa Elisa plant produces about 66 million gal of ethanol per year. That's a small contribution to Brazil's 2006 total output of 4.5 billion gal, as reported by the Renewable Fuels Association, the national trade association for the U.S. ethanol industry. By comparison, U.S. bioethanol production, which caught up with and then surpassed Brazil's in 2006, was 4.9 billion gal. Those numbers will continue to rise rapidly. For example, U.S. production should top 6 billion gal in 2007.

The U.S. and Brazil together produce about 70% of the world's bioethanol, but they produce and use it in slightly different ways. For example, U.S. bioethanol is made from cornstarch, which involves a slightly more complicated process. Enzymes are needed to convert the starch to glucose, which is then fermented. This extra step means the Brazilian way is more efficient and less expensive.

In the U.S., gasoline is typically blended with 10% ethanol (E10) where required to help curb smog, without any engine modification needed for most automobiles. But gasoline blended with 85% ethanol

(E85) is starting to make inroads for use in "flex-fuel" vehicles. These cars and trucks have sensors to adjust the timing of spark plugs and fuel injectors so the engine runs smoothly no matter what percentage of the fuel might be bioethanol.

In Brazil, ethanol for flex-fuel vehicles is blended with gasoline in different proportions, up to 25% ethanol (E25). Another type of fuel in Brazil is hydrated bioethanol, which is pure bioethanol (E100) that contains a small amount of water.

Ethanol is hygroscopic and attracts moisture from the air. In the U.S., this moisture has been considered a problem because it can lead to corrosion in fuel pipelines, storage tanks, and car engines. For that reason, bioethanol in the U.S. is transported separately to local distributors before it's blended with gasoline, a step adding to the cost. In Brazil, hydrated bioethanol seems to be working fine, Dabdoub and others pointed out.

Overall, some 28% of automobiles in Brazil are capable of running on one of these bioethanol options. Bioethanol currently makes up 12.6% of transportation fuel in Brazil and 3.5% in the U.S.

As for the Santa Elisa plant's bagasse—the fibrous, grasslike fluff left over from the sugarcane crushers—it's sent along on conveyers to a set of glowing furnaces where it's burned to produce steam. The steam powers the crushers and other equipment at the facility and turns a set of generators to make electricity.

The residual ash from the furnaces is spread on sugarcane fields as fertilizer, and in most cases, it's all the fertilizer that's needed. In the U.S., on the other hand, the residual biomass from corn-to-ethanol processing, called dry distillers grains, is usually sold as animal feed. In the future, bagasse and dry distillers grains could be converted to fuels or chemicals by enzymes or be gasified or pyrolyzed to obtain fuels.

While bioethanol plants in the U.S. typically only consume electricity, the Santa Elisa plant generates 60 MW of electricity. About 19 MW is used to power the plant, and the remainder is sold to the local power grid.

As one Santa Elisa engineer told the group: "We squeeze every drop of potential energy out of every stalk of sugarcane."

The first thing scientists offer to tell you in Brazil is that increasing biofuel production not only is possible and necessary, but that it can be done without cutting down the country's precious rainforest. Land use is a touchy subject in Brazil because of pressure from international environmental advocacy groups, which are concerned that Brazil's environmental laws are not always well-enforced. And during nearly every stop of the Brazilian tour, the U.S. delegation gleaned more information about the tension.

Total land area in Brazil is about 851 million hectares (one hectare is about 2.5 acres), about equal to the size of the 48 contiguous U.S. states. Most of Brazil's 188 million people live in the southern states, which include the megacities of São Paulo and Rio de Janeiro. Around 500 million hectares are designated as protected lands, including much of the Amazon basin, which occupies most of the northern half of the country. Most of the remaining land is available for raising cattle or growing crops.

STEVE RITTER/C&EN

TALL ORDER Ethanol distillation columns rise above trucks loaded with sugarcane at a Santa Elisa refinery. The facility coproduces sugar, ethanol, and electricity, an integral combination for Brazil's bioenergy industry.

The mix of crops grown in Brazil has shifted as economic conditions have changed over the years, Dabdoub explained one day as the tour group barreled down a São Paulo highway. In the 1950s and before, dating back to the colonial period, coffee and beef were the key agricultural products. In the 1960s, higher soybean prices encouraged farmers to begin planting more soybeans, he noted. Brazil also began planting more oranges when farmers realized they could gain an economic windfall whenever a spring freeze reduced the crop of Florida oranges.

But since the 1970s, when Brazil started the alcohol program during the global en-

"We squeeze every drop of potential energy out of every stalk of sugarcane."

ergy crisis, sugarcane has taken the lead. "Wherever sugarcane can be grown, people plant sugarcane," Dabdoub said. In the U.S., it's now the same situation with corn.

One key to Brazil's biofuels future is that about 100 million hectares of land is available for agricultural production. During a workshop at the State University of Campinas, one of Brazil's leading research universities, Luís A. Cortez laid out for the tour group an ambitious bioethanol proposal for Brazil that counts on using some of that land. Cortez, the university's institutional and international relations coordinator, described a feasibility study on replacing 10% of world gasoline demand with bioethanol by 2025.

"Brazil is the only country that can produce significant volumes of bioethanol for the world market," Cortez pointed out. In 2006, Brazil exported about 20% of its bioethanol, with most of it going to the U.S., he said. But realistically, Brazil might only be able to supply half of the 2025 target using current technology, some 27 billion gal, while other countries might be able to contribute the other half, he added.

FOR BRAZIL, that would require 615 ethanol plants—about 400 plants are expected by the end of this year—and 22 million hectares of sugarcane, nearly four times the current crop. Each new refinery would cost some $140 million to build and operate, but the overall program would generate an estimated $31 billion in annual exports for Brazil and create 5.3 million jobs, a significant boost for the still-developing country, Cortez said.

During the discussion at the Campinas workshop, Dabdoub took a verbal jab at the U.S. for its tariffs and subsidies on biofuels that are hurting Brazil's efforts to export ethanol. In the U.S., ethanol and biodiesel can't compete against fossil fuels, even with renewable fuels standards in place, so the federal government claims a 54-cent-per-gal tariff on imported ethanol and provides a 51-cent-per-gal credit for blending ethanol into gasoline, he pointed out.

"That's a $1.05-per-gal hit against Brazilian ethanol," Dabdoub said.

Although Dabdoub did not mention it, the U.S. also has a $1.00-per-gal tax credit for blending biodiesel with petroleum-derived diesel. This tax incentive has become controversial, even among U.S. oleochemical makers, because it could threaten supplies of U.S. beef tallow, the rendered fat from cattle used to make soap, personal care products, and now biodiesel (C&EN, June 4, page 25). Supply is not an issue in Brazil, which is by far the world leader in beef production, providing about twice as much as the U.S.

Such practices are hurting the U.S. by driving up fuel prices and holding back Brazilian efforts, Dabdoub said. "We can build a world energy market, but it won't work if the U.S. market is closed."

Another stop on the Brazil biotour was Biocapital's biodiesel plant in Charqueada. This facility is one of the first of many anticipated Brazilian facilities that will make biodiesel from vegetable oil and/or animal fat. The U.S. contingent was greeted by Roberto Engels, the company's constantly smiling president. Engels indeed has much to smile about, as the future for biodiesel looks bright in Brazil.

"The potential of biofuels is huge if you work diligently and seize opportunities," he said.

Engels and his staff walked the tour group through the facility and explained the opportunities the company went after to develop its biodiesel production process. The Biocapital plant, which has been producing biodiesel for only a few months, was converted from an existing facility that produced essential oils. Retrofitting chemical plants to make biodiesel is becoming a common practice worldwide (C&EN, Feb. 12, page 53).

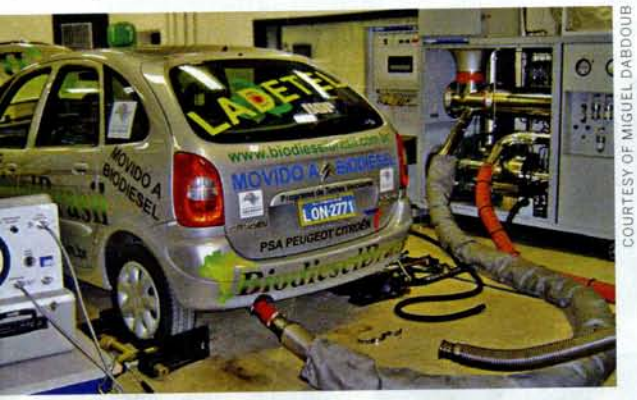
Biocapital uses beef tallow as the starting material, as currently it's the least expensive source of triglycerides for making biodiesel. The facility could use soybean or other plant oils, Engels noted, and in the future the feedstock choice will continue to be driven by economics.

Converting beef tallow into biodiesel is carried out by the standard transesterification process that lops off the long fatty acid

chains of the triglyceride to form methyl esters, which make up biodiesel, Engels explained. The process uses 2% sodium methoxide ($NaOCH_3$) as a catalyst and methanol as a solvent. After a 30-minute reaction, the crude biodiesel is separated from the methanol, the by-product glycerol (1,2,3-propanetriol) that comes from the propyl backbone of the triglycerides, and other residues.

The biodiesel is purified by vacuum distillation to give the final product. Biocapital's plant is a bit unusual in this regard, Engels noted, as most biodiesel plants rinse the biodiesel with water to remove impurities. The distillation columns were left over from the original plant design, so the process engineers decided to make good use of them to produce an extra-pure biodiesel, he said.

The collected methanol is recycled for subsequent batches, while the glycerol is sent to storage tanks and subsequently loaded onto tanker trucks to be sold. As biodiesel production has increased in the past couple of years, a glut of glycerol has flooded the market, and the chemical industry has been scrambling to figure out what to do with it. A handful of possible value-added uses for glycerol have been developed, including using it as a feedstock to make propylene glycol and epichlorohydrin (C&EN, May 7, page 14).



COURTESY OF MIGUEL DABDOUB

CLEANING UP A LADETEL test car running on an experimental blend of biodiesel gets a thorough exam to check on engine emissions and performance.

Biocapital's plant currently has capacity to produce 60,000 metric tons (18 million gal) of biodiesel per year, which is trucked to distributors. Biodiesel typically is measured in metric tons, rather than by volume. As for Biocapital's future, a capacity expansion is starting to take shape adjacent to the current facility. It will increase production up to 252,000 metric tons (76 million gal) per year by early 2008, Engels noted. Down the road, Biocapital has ambitious plans to become an integrated biofuels company, producing both biodiesel and bioethanol. The bioethanol could be sold separately or eventually could replace the petroleum-derived methanol in the process. But for now, methanol is cheaper.

"Brazil is heavily dependent on diesel, which accounts for 58% of Brazil's transportation fuel market," Engels pointed out to the U.S.-Brazil tour group. That's about double the percentage used in the U.S. and about the same as in Europe, he said.

Brazil currently imports about 15% of its diesel, but the progressive nation is moving quickly to remedy that situation, Engels noted. By 2008, Brazilian diesel must include 2% biodiesel, which works out to about 210 million gal of biodiesel per year; by 2013, the mandate increases to 5%, or about 635 million gal per year.

By comparison, biodiesel production in the U.S. was about 250 million gal per year in 2006, according to the National Biodiesel Board. The trade association projects annual U.S. biodiesel production will climb to 650 million gal per year by 2015.

Brazil has plenty of oilseeds to choose from when it comes to making biodiesel: soybeans, cotton seeds, sunflower seeds, rapeseeds (canola), castor beans, macadamia nuts, peanuts, and sesame seeds. These seeds all produce around 0.5 ton of oil per hectare per year, Dabdoub said. But in Brazil, the goal is to push up production to 2 tons of oil per hectare within the next 10 years and 5 tons per hectare within 30 years, he added. One way is to improve oil content with improved varieties of plants, but a more viable option is to use plants that have higher oil content to start with.

Currently, 96% of vegetable oil in Brazil comes from soybeans, about 3% from palm oil, and the remaining 1% from a combination of oilseeds, Dabdoub said. Rather than sticking with tradition and trying to improve soybeans, the "real potential" is in palm oil or that remaining 1%, he stressed.

Dabdoub is particularly enamored with the palm oil for now. The fruit and kernels from the introduced African palm and from a native palm, called babaçu, have up to 12 times more oil content than soybeans, he explained. These palms are already widely grown in Southeast Asia, Africa, and in the warm tropical region of northern Brazil, and the volume of oil produced globally from them is second only to soybean oil, he said.

Dabdoub acknowledged some technical challenges in using palm oil for biodiesel. For example, palm trees take about five years to get established before the fruit can be harvested. But once the trees reach peak production after 20 years, they can produce a lot of oil.

ANOTHER ISSUE for biodiesel made from pure palm oil is the oil's high melting point, which means it can't be used for biodiesel in many parts of the world. The problem became evident one cool morning during the tour, when the temperature was about 10 °C (50 °F). Palm biodiesel in a 5-L container in the back of one of the LADETEL cars was solid. Later in the morning, as it warmed up, the diesel was a liquid once again.

The difference in the biodiesel derived from beef tallow and from palm, soybean, and other oils is the different lengths of, and the number of double bonds in, the long hydrocarbon ester chains that make up the oil. Despite the temperature issue, Dabdoub and his group are still pursuing palm biodiesel because it can be used in warm tropical regions or blended in small amounts with biodiesel produced from soybeans or other oilseeds.

After returning home, several members of the U.S. delegation reflected on their experience in Brazil. "The most impressive aspect of the Brazilian bioenergy industry is the integration of sugarcane production, processing, equipment manufacture, reuse of residue as fertilizer, and generation of electricity from the bagasse," commented Foster A. Agblevor, an associate professor of biological systems engineering at Virginia Polytechnic Institute & State University. Agblevor is studying biochemical and thermochemical conversion of plant and animal wastes into fuels and chemicals.

"With their approach, progress is more rapid than in the U.S., and the system doesn't require any subsidy," Agblevor told C&EN.

The use of heterogeneous catalysts to transform triglycerides to biodiesel also is a very strong area, he added. On the other hand, progress in incorporating biotechnology "is rather slow," he said. There's little research in thermochemical processing of biomass, and research in cellulosic ethanol production is essentially "nonexistent." But research collaborations can be set up

easily to capitalize on the strength of the two countries, he noted.

The involvement of undergraduate students in biodiesel research was impressive, Agblevor added. "Although we have the NSF undergraduate research experience in the U.S., the Brazilian system is more comprehensive. We could learn something from them."

"The trip to Brazil was both fun and educational," said William R. Sutterlin, chief executive officer of Renewable Alternatives, Columbia, Mo., a company that is turning the glycerol by-product from biodiesel into value-added chemicals and materials. "It was truly impressive to see agriculture playing such a vital role in the lives, economy, and governmental policies.

"The Brazilians are showing that sugarcane as a source of ethanol and electricity is a sustainable and efficient process," Sutterlin continued. "The way the sugar is extracted, the bagasse is burned to generate electricity, and the ash put back onto the fields is a process that leaves little waste. Unfortunately, in the U.S., the corn fermentation route to produce ethanol is nowhere near as efficient as sugarcane fermentation. I wish we could grow sugarcane in the Midwest."

Edwin S. Olson, a chemist at the University of North Dakota and chair of the ACS Division of Fuel Chemistry, said it was "fascinating to see the revitalization of the Brazilian economy" relative to a trip he made to Brazil several years ago.

STEVE RITTER/C&EN

SWEET FLUFF Fibrous remains of processed sugarcane, called bagasse, are burned in Brazil to generate electricity. In the future, enzymatic processes might be used to convert the cellulosic material into additional ethanol.

"The growth is related to the increased production of biomass fuels, but behind that stand people with a vision of progress and commitment to investment in new vehicles, efficient plants, and development of global markets," Olson added. Two of the many research opportunities that stand out for him are better utilization of biomass to produce chemicals as well as fuels and developing diversity in plant and algal oil production and its conversion to fuels.

"My hope is that the team assembled for the tour and symposium can continue to serve as catalysts for the development of research on biomass-derived fuels and chemicals in Brazil and the U.S.," Olson said. ■