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THE EBInsider

THIS SPECIAL ISSUE OF THE EBINSIDER IS DEVOTED TO THE HISTORIC FIRST INCLUSIVE RETREAT OF THE ENERGY BIOSCIENCES INSTITUTE, HELD AT THE IHOTEL AND HOSTED BY THE UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN JUNE 19 - 22. IN WORDS AND IMAGES, THIS EDITION IS DESIGNED TO CONVEY THE EXCITEMENT AND TEAM-BUILDING SPIRIT THAT WAS FELT BY THOSE WHO ATTENDED.

THEY CAME, THEY TALKED, THEY BONDED

EBI SCIENTISTS, STUDENTS, STAFF USE RETREAT TO RECALIBRATE EFFORTS AND COMPARE NOTES

They came from across the country and across the campus—agronomists and biochemists, plant physiologists and chemical engineers, economists and climatologists, professors and students—to engage in a weekend of around-the-clock conversations about where they are and where they go from here.

"They" were the members of a potentially world-changing research partnership called the Energy Biosciences Institute. The location was the University of Illinois' IHotel conference center in Urbana. And the event was the first inclusive retreat since the EBI was established in late 2007.

The host of this historic gathering, Illinois professor and EBI Deputy Director Steve Long, outlined the purpose of the program at the opening session on June 20: "…to figure out how we work together as a team, to find the opportunities where one-plus-one is more than two, and to see where we can find synergy in place of duplication. This (retreat) will help us

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NEW RESEARCH PREPROPOSALS DUE AUGUST 10

The Energy Biosciences Institute has issued a call for new research proposals in the areas of 1) novel aspects of energy biosciences, and 2) development of lignocellulosic biofuels. Funding of up to $7.5 million is available for the period of 2010–2013, and three-page preproposals are due from faculty no later than August 10. To be eligible, faculty must have primary appointments at one of the partner EBI institutions.

Faculty submitting preproposals considered a good fit for the EBI's goals will be invited to submit a more detailed proposal, including a proposed budget and timelines. A confidential peer-review process will identify successful proposals for funding consideration by the EBI Executive Committee.

Preproposals should be submitted online at www.ebiweb.org/cgi-bin/admin/logon.cfm. More information about the scope, format, timelines, procedures, and related matters can be found on the EBI public web site (www.energybiosciencesinstitute.org) under "Funding Opportunities." Questions should be addressed to EBI Assistant Director Susan Jenkins at sjenkins@berkeley.edu.

INSIDE THE INSIDER

FEEDSTOCKS: MINIMUM INPUT, MAXIMUM YIELD

OVERVIEW: STEVE LONG

Steve Long

EBI Deputy Director Steve Long outlined the criteria that new biofuel feedstocks had to meet: no displacement of food crops, no major water requirements, and a reduction in net greenhouse gas (GHG) emissions.

"One of the most important characteristics for feedstocks is yield—how much can be produced per hectare of land," he said. "The biofuels we seek don't need large nutritional or energy inputs." Long said the ideal crop will also have a high energy conversion efficiency; for example, the highly regarded Miscanthus perennial grass has a solar conversion rate of 70 percent, which is 60 percent more productive than corn.

Miscanthus giganteus, a sterile hybrid, has other advantages, according to Long: a root system that binds the soil and prevents erosion while providing nutrients to the plant, high productivity in temperate climates, and sustainability via carbon sequestration. Researchers are modeling Miscanthus for solar radiation, water content, and soil depth to predict yields under varying conditions. Comparative trials are set up throughout the U.S.

The agriculture specialists from Illinois are focusing on four aspects of biofuel plants in the EBI program: feedstock production and agronomy, engineering solutions for biomass production, pests and pathogens, and feedstock genomics.

As a relatively new crop, Miscanthus hasn't developed large populations of pests and pathogens yet. However, as the acreage increases, such problems will arise, so understanding them at this stage will lead to preventative care and possible resistant strains. Viruses, bacteria, nematodes, and insects are all possible candidates being investigated.

PANEL: STEVE MOOSE AND K.C. TING, UNIVERSITY OF ILLINOIS; SHEILA MCCORMICK, UC BERKELEY

(From left) Steve Moose, K. C. Ting, Sheila McCormick

Moose, who leads the feedstock genomics program, is looking at the genes that underlie interesting traits. Through biotechnology, the good traits might be enhanced, the bad ones eliminated. But it's a challenge. He's spent much of his career studying the genetic characteristics of corn, but *Miscanthus giganteus* has a genome the size of three corn genomes.

So far, thanks to new sequencing technology, he and his team have captured about 63,000 genes or fragments, about 12,000 of those long enough to use in experiments. Computers have produced 73 million genome "reads," with genetic markers in the thousands. That's still only about 2 percent of the entire Miscanthus genome, but he hopes to complete a draft of it over the next year.

Ting is studying the biomass cycle from crop to refinery, looking for improvements in efficiency along the way. They could come in crop health and growth, harvesting, transportation, or storage. He uses state-of-the-art monitoring tools that include a rotating tower camera and a mini-helicopter with remote sensing equipment. By the end of this year, a 40-by-60-foot feedstock storage research facility will be built on the Energy Farm.

"We are developing system informatics and decision support systems to see how all of these things affect the future efficiencies," Ting said. "We set up scenarios to identify missing links and help managers determine the best supply and value chain."

A plant reproduction specialist, McCormick said she is tending to 150 *Miscanthus sinensis* plants in an Albany, CA, greenhouse and studying their pollination and self-incompatibility. Since the pollen is very short-lived, only a few of the plants are usable for study on any one day.

Through genetic mapping and comparisons with the maps of ryegrass and rice, she said, she hopes to find the key to overcoming self-incompatibility in order to enhance plant fertility and rise above the reproductive barriers that Miscanthus and other feedstocks might face.

PLANT DEPOLYMERIZATION: BREAKING DOWN WHAT NATURE HAS EVOLVED

OVERVIEW: JAMIE CATE

Jamie Cate

If anyone knows how difficult it will be to rapidly depolymerize cellulose and lignin into fermentable sugars, it's Jamie Cate. The UC Berkeley biochemist spent the first year of his EBI program trying to study the function of cellulosomes, an assembled group of enzymes that appear to be key to the genetic breakdown. But when it came to manipulating those proteins, he said, he "hit the wall." He lacked the genetic tools to manipulate the genome, and the interplay of enzymes in the hydrolysis was more complex than he imagined.

Now, in a collaboration with EBI investigator Louise Glass and colleagues, he and his team are focusing on *Neurospora crassa*, a model fungus that breaks down woody fiber, and the way its enzymes, transporters, and regulators function. The excellent genetic resources available in *Neurospora* have allowed the researchers to undertake a systematic analysis of what each gene contributes to biomass degradation.

"Any given organism secretes dozens of proteins to break down plant cell walls," Cate said. "We don't understand many of them. To try to manipulate a given organism can be rate-limiting. And to achieve efficient depolymerization, we need a lot of enzymes. So how can we increase the quantity by at least an order of magnitude?"

He said the depolymerization team is "casting a wide net." One group, led by DOE Joint Genome Institute (JGI) Director Eddy Rubin in collaboration with University of Illinois microbiologists Rod Mackie and Isaac Cann, is studying cow rumen microbes. Cann is also investigating thermophylic organisms that produce ethanol. UC Berkeley's Doug Clark and Harvey Blanch are leading the efforts to improve enzymes by building a model system of how they work. And other groups are probing the physical, biological, and chemical basis for cellulase activity.

PANEL: MICHELLE CHANG, UC BERKELEY; EDDY RUBIN, JGI AND BERKELEY LAB; ISAAC CANN, UNIVERSITY OF ILLINOIS

(From left) Michelle Chang, Eddy Rubin, Isaac Cann

Chang explained the challenges of decomposing lignin, the complex binding compound in plant cells that can constitute up to 30 percent of the cellulosic biomass. She is studying the relationship between the lignin structure and the multi-enzyme breakdown pathways, looking at both fungal and bacterial systems.

"We don't understand the chemistry yet," she said, "but when we do, we can look at it in terms of chemical reactions and breakdowns."

Rubin said his JGI team is developing a large catalogue of full-length lignocellulolytic genes. "We are looking at microbes that participate in the deconstruction of energy feedstocks and finding the genes relevant to the process," he said. Much of that data comes from the rumen of cows that are fed switchgrass.

"We've done 18 billion base pairs of switchgrass-associated rumen microbes" within the JGI's high-throughput sequencing program, Rubin noted. "The challenge now is analysis of the data. It takes huge amounts of data-intensive computing to pull out the genes we are interested in. Eventually we can begin to assemble whole microbial genomes."

And he added, "Nature has evolved through the millennia the ability to break down biomass, so we are just scratching the surface. We need to move from genomic data to enzymological data."

Cann's enzyme discovery group is seeking effective cellulases and hemicellulases. "Our strategy is to use isolated organisms and make a set of enzymes that break down cellulose, and another set that break down hemicellulose," he said. "So it's an enzyme mix for hydrolysis to monosaccharides." Early results are proving the principle with small amounts of substrate by increasing the release of xylose and arabinose, two of the fermentable sugars in cellulose.

ECOSYSTEM SERVICES:
SEEKING SUSTAINABILITY, ENVIRONMENTAL INTEGRITY....

OVERVIEW: EVAN DELUCIA

Evan DeLucia

How will the deployment of biofuel feedstocks on the landscape affect land, water, and air? That's what Illinois environmental scientist Evan DeLucia and his EBI colleagues in the Environmental Impact and Sustainability group are trying to predict.

"We want to close the biochemical cycles for carbon, nitrogen, and water," he told his EBI colleagues. "By studying ecosystems, we can measure the intake and release of these elements in the plants, in the soil, and in the atmosphere." In doing so, they hope to find a feedstock that adds nitrogen and carbon to soil fertility, balances carbon uptake and outgo, and minimizes greenhouse gases and water use.

Those measurements will largely be made on the EBI Energy Farm in Illinois. "There are no major studies yet on adjacent plots of systems," DeLucia said. "But in our experimental plots, we will be studying corn, Miscanthus, switchgrass, and restored prairie side-by-side."

The instrumentation in those fields is extensive and sophisticated. DeLucia described one system called "eddy covariance," in which air moves over a surface in giant ovals, up and down, and sensors rapidly capture the carbon going in and out of a planted zone. A tile drainage system has been installed under the plots, which, he explained, directs the leached runoff into wells for automated sampling and chemical analysis. Towers equipped with sonic anemometers, infrared gas analyzers, laser-based nitrogen flux probes, and soil respiration monitors are all technologies crucial to the search for a "green" biofuel feedstock.

His colleagues are also looking at the non-plant biology of the system. Microbial ecologist Angela Kent is focusing on nitrogen-fixing bacteria. Others are studying microbes and arthropods. Some 14,000 insects have been collected in three different types of traps and are being identified, possibly enriching the biodiversity in new biofuel feedstocks.

PANEL: CARL BERNACCHI, UNIVERSITY OF ILLINOIS; NORM MILLER, UC BERKELEY AND BERKELEY LAB; ARPAD HORVATH, UC BERKELEY

(From left) Carl Bernacchi, Norm Miller, Arpad Horvath

Plant biologist Bernacchi explained how he is trying to extend the plot-sized investigations at the Energy Farm into a regional modeling of potential environmental impacts of feedstock production. Those models use inputs from the atmosphere, land surface, natural vegetation, and below-ground carbon and nitrogen.

"We will incorporate our measurements in Illinois and scale them up to the region, shifting them throughout an annual time cycle," he said. "The Energy Farm will give us a more reliable data set. Then we can incorporate fluxes at other sites throughout the United States."

Climatologist Miller is also using models—five of them, in fact—to conduct geospatial analysis, bioenergy crop modeling, and agro-economic analysis around the globe. One of the first tasks is looking at marginal lands, which are prospective targets for growing Miscanthus and switchgrass. In coordination with a United Nations group studying bioenergy and earth sustainability, he said, they are exploring new and better modeling techniques by assimilating the elements of existing systems.

"EBI is now evaluating the models," Miller said. "There are 43 parameters that potentially vary by vegetation type. We need to develop decision support tools to help identify prioritized land based on crop value, pasture value, and optimization of soils."

Horvath, environmental engineering colleague Tom McKone, and a team of 17 are studying the entire life cycle of a biofuel and are working to provide models and realistic numbers for each stage of development and use. "We will rely on the entire EBI for good numbers, in production, conversion and processing, storage, transport, distribution, and combustion and use," he said. "All of these will result in human health and ecosystem impacts."

The challenge comes in what he termed the "uncertainty" of the data and "scalability issues." The overarching metric is money—the total cost of ecosystem services and environmental impacts. Metrics will be developed for human health, natural environments, natural resources, man-made environments, and life-support systems.

"We are also tasked with tracking emissions, from source to impact, how they bioaccumulate, uptakes and doses," he said. "In protecting these services, we have to worry about biodiversity, air cleaning, water retention, erosion control, and carbon sequestration. Agriculture systems should be optimized by using this life cycle analysis."

THE VIEW FROM BP:
PROMISING FUTURE FOR EBI, BIOFUELS .....

David Eyton

David Eyton, BP's Vice President for Research and Technology, was one of the more interested attendees at the EBI retreat, not just because he's the new chairman of the Institute's governance board, but also because his energy company likes to see profit from its investments. The EBI happens to be one of its largest, at $500 million.

And he likes what he sees.

"This is a very grand scale of enterprise," he told the conferees on the first day of meetings, "and I have no doubt whatsoever that (the EBI) will make a large impact on the world. You cannot underestimate the importance of a broad holistic understanding of the impact of biofuels on society. Politicians and the public need to know what is and is not fact-based."

He added a hearty "well-done to everyone for coming out of the block so quickly. We are very proud of what has been achieved here."

Eyton presented his vision of BP's energy portfolio, indicating the company is "quite bearish in the short term, given the fluctuation in oil prices." His prediction: "The world is looking to, and believing in, a more renewable and sustainable energy above and beyond fossil fuels. But (fossil fuels) will continue to comprise a large portion of the energy industry."

He said he expected to see significant progress on renewable energy technologies by 2030, but that BP is more interested in what happens between now and then—will there be more carbon dioxide in the atmosphere? And what does that mean for the energy future of the planet?

"We are focusing on places that we believe will have government support, on where we are most confident we can make things work," Eyton said. "In order of potential, we are investing in biofuels, carbon management, solar, and wind. BP is taking equity interest in (biofuel) companies, (but) we are more comfortable with more open collaborations and believe in their ability to make a difference in the world—like the EBI."

Eyton added that the EBI is a new model for BP, and "we have to learn by doing as things arise, and try them out for real. We are very excited about this journey."

Ian Dobson, Eyton's BP colleague in the strategy, policy and technology division, was the final evening's dinner speaker and offered a PowerPoint "tour" of the company's biofuel business units.

"Biofuels is actually a great business to be working in, because so much in energy companies is not high-growth these days," Dobson said. "Technology is absolutely essential to this industry."

BP's biofuel plan between now and 2020, he said, calls for producing new fuels equivalent in energy to 4½ giant oil fields. Through both corporate and academic partnerships, he said, the company is hoping to produce 70 billion gallons of biofuel by the end of the next decade.

According to Dobson, several hurdles have to be overcome for the endeavor to be successful—including the "blend wall" limits of current auto engines, the underinvestment by other members of the global energy market, the emerging issues related to environmental impacts and land use, and the tariff walls being imposed by some countries. Access to affordable feedstock will be key, he added.

"Regulatory support is solid, and the market is going to be big," he concluded. "Technology is advancing quite apace. Renewable fuels should be competitive with fossil alternatives by 2020. (Biofuel) has a healthy, long-term future."

MEHR: ENLISTING MICROBES IN EFFORTS TO ACCESS 'LOST' ENERGY

OVERVIEW: TERRY HAZEN

Terry Hazen

The mission of the newest EBI program, Microbially Enhanced Hydrocarbon Recovery (MEHR), might at first glance seem to run counter to EBI's primary search for alternatives to fossil fuels. But BP Technology Vice President and EBI Associate Director Paul Willems doesn't see it that way.

"We won't be turning carbon off completely," he told the retreat attendees about the world's future energy needs. "But we need to get energy from carbon-friendly sources. In the transition (from fossil to biofuels), we need a low-energy way of recovering oil."

MEHR program principal investigator Terry Hazen, senior earth scientist at Lawrence Berkeley National Laboratory, said his team's objective is "to understand the microbial community and function" in the deep subsurface wells that yield petroleum. He noted that nearly 65 percent of the oil discovered in reservoirs throughout the world is inaccessible and unrecoverable. Those untapped reserves are the target for MEHR.

"Sometimes it works, sometimes it doesn't, and we don't know why," he said of the use of microbes to extract the difficult deposits. "The variables are the science we have to pursue." The core study areas include reservoir geology and geochemistry, ecogenomics, and flow rate and mechanisms.

"We hope to identify pertinent novel model species and gain an understanding of in situ biorefinement," Hazen said. "We will try to find bacteria we could stimulate to 'sweeten' the oil (i.e., reduce the amount of sulfur compounds such as H2S) and reduce the viscosity, or convert it to methane and then push it out of the formation. If we could improve the oil recovery by just 5 percent, it would mean a tremendous amount of oil."

They have already begun field testing at a Decatur, IL, injection well on the Archer Daniels Midland ethanol plant site. The well was drilled for carbon storage and capture tests, and Illinois geologist Bruce Fouke and his team are getting ready to study the underground geobiology networks. Members of the Berkeley contingent at the retreat took a June 22 field trip to the site.

Hazen said that the expected outcomes of the program include the identification of pertinent novel model species, the quantitative understanding of the deep subsurface environment, and the development of predictive models for use by the oil industry.

BIOFUEL CHEMISTRY: BIOLOGY'S INVALUABLE PARTNER

OVERVIEW: ALEX BELL

Alex Bell

While the EBI mission is to explore "the application of advanced knowledge of biological processes, materials and mechanisms to the energy sector," the Institute's leadership has not forgotten chemistry's role. The EBI has also funded non-biological approaches to deconstructing biomass and converting the products into biofuel alternatives.

UC Berkeley chemical engineer Alex Bell discussed one of those approaches: the potential use of ionic liquids (IL) to dissolve cellulose. He explained that the advantage of ILs—salts containing organic cations—is that at or near room temperature, they can dissolve virtually all components of biomass.

"Cellulose is a crystalline solid held together by strongly interacting hydroxyl groups," he explained. "Ionic liquids break up these interactions. Once the cellulose is dissolved, it can be hydrolyzed with the aid of an acid catalyst to produce glucose." The glucose produced can be converted to a variety of products by combinations of acid and metal catalysts. Bell and his team are exploring how this approach can be used to produce fuel molecules that meet the energy and performance requirements for a biofuel.

"It is too early to assess the ultimate viability of the approach and its cost," he noted of the non-enzyme depolymerization technique. But early research results indicate the option is certainly worth pursuing, either as a stand-alone chemical process or in conjunction with biological methods.

Alex Bell (right) and UC Berkeley chemical engineer Alex Katz discuss poster with BP's Eric Mack (left)

Field of Dreams

A VISIT TO THE FARM

(Top) Original Miscanthus site established in 2002; (Below) Unmanned Aerial Vehicle (UAV) monitors crops from the air

Those attending the research retreat who had not yet been to the EBI Energy Farm piled into buses on a spring afternoon in central Illinois to get up close and personal with Miscanthus, switchgrass, prairie grasses, and maize. Approximately 100 different species and varieties of feedstocks are being grown and monitored in the 280-acre outdoor laboratory, Feedstock Production/ Agronomy Program leader Tom Voigt of the University of Illinois told the visitors.

The Energy Farm will eventually become a one-half-square-mile living

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'Micro-plots' study insect affects on biomass

Miscanthus, before and after harvest

library of potential biofuel feedstock—a test site for plant yield, planting and harvesting equipment, and agronomy techniques, as well as a classroom for visiting schools, extension groups, and service organizations. And as the crops grow, EBI researchers maintain constant surveillance above and below ground.

Berkeley city slickers touched leaves of the young *Miscanthus x giganteus* (Mxg) plants, which were standing at roughly half the height of their eventual 13 vertical feet and by October would yield as much as 30 tons of feedstock per hectare, according to EBI Deputy Director Steve Long.

Mxg isn't the only thing growing. The Farm itself will be 340 acres in size when the final plot of land is acquired next year. And by the end of 2009, a new permanent building at the Energy Farm will have been constructed to host a feedstock preparation lab, equipment storage, sample archives, and staff offices.

Deputy Director Steve Long talks about Miscanthus

Agricultural engineer Alan Hansen displays a handful of feedstock rhizomes as part of the harvesting equipment display

A VISIT TO THE FARM (CONT'D)

Feedstock specialist DK Lee addresses the tour group

UI horticulturalist Tom Voigt surveys the farm

Postdoc Sarah Davis points out farm plots on tour

BIOCONVERSION:
ENGINEERING MICROBES TO BUILD A BETTER FUEL

OVERVIEW: ADAM ARKIN

Adam Arkin

Adam Arkin titled his talk "An Idiosyncratic View of Fuel Synthesis Challenges," but there's nothing quirky about the goal of EBI's bioconversion program—to engineer new strains of microbes that can maximize the fermentation of feedstock sugars into energy fuels. "Existing biofuels are not optimally produced," said the UC Berkeley systems biologist. "The fuel has to be scalable, it has to use the full value of the gasoline, and has to be less energy-intensive to produce. Current fuels are often toxic in high concentrations and are not transportable by traditional means."

That's a tall order, and it's made more complicated by the fact that the microorganisms also have to overcome the presence of toxic inhibitors, the result of pretreatments of the cellulose prior to deconstruction. But a team of researchers, including Illinois' Yong-Su Jin, Huimin Zhao, and Chris Rao, and the Joint Genome Institute's Thanos Lykidis, are looking for the pathways that will lead to the efficient production of ethanol or other high-density fuels.

Few natural bacterial systems hold the promise of efficient conversion of biomass to fuel, but *Zymomonas mobilis* is one of them. Arkin said *Z. mobilis* is known for its high ethanol yields, high tolerance levels, and high fermentation selectivity. His team's next steps will be to create a full *Z. mobilis* library, to genetically screen strains "like crazy," and to identify relevant genes and fermentation pathways. Results will be posted on Microbes Online, a functional database that features tools to enable comparisons of genes and genomes. Tools are also being built for enzyme and pathway engineering once the predictive analysis is completed.

PANEL: HUIMIN ZHAO AND CHRIS RAO, UNIVERSITY OF ILLINOIS; THANOS LYKIDIS, JOINT GENOME INSTITUTE

(From left) Huimin Zhao, Chris Rao, Thanos Lykidis

Brewer's yeast is an effective agent in ethanol fermentation, robust and tolerant, with a well-known physiology. It can work on so-called C6 sugars—those with six carbon atoms, like glucose—but it can't break down C5 sugars like xylose and pentose. Huimin Zhao's group is working to engineer a pathway that will also work on the residual sugars in cellulose to maximize yield.

"We've developed quite a few tools," Zhao told the group, "like a pathway (DNA) assembler, a one-step genome modification method for removing and inserting a gene rapidly, and a metabolic flux analysis tool. Also, genome-scale modeling helps in assembling pentose sugar utilization pathways."

Biomolecular chemist Rao is also working to engineer microbial strains optimized for large-scale fermentation, specifically tracking the transport of sugars "and trying to understand gene dynamics which could lead to a strain for efficient multiple sugar utilization," he said. Using the model organism *E. coli,* Rao and his team have already studied nearly 30 sugar transporters to the point where "we now understand the regulation, and now we must try to crack the hierarchy."

He has focused on the sugars arabinose and xylose, studying gene expression at single-cell resolution.

Lykidis is interested in another bacterial path to biofuels—the transition of sugar into lipid molecules, like fatty acid esters. From a list of genomes, he found one enzyme that seemed to do the job. "Now we are looking at bacterial response to lipid accumulation, and the genetic basis for this," said the JGI biochemist. "We know why we humans accumulate triglycerides, but we don't know how it happens in certain bacteria."

Their goal is to be able to generate enough lipids for production of diesel and gasoline extenders by microbial cultures. Approximately 60 percent of the transportation fleet in Europe and a third in the U.S. is dependent upon diesel fuel, which cannot be blended with ethanol.

SOCIOECONOMICS:
MAKING SURE BIOFUEL IMPACTS ON SOCIETY ARE POSITIVE

OVERVIEW: MADHU KHANNA

Madhu Khanna

Underlying the prospect of a promising biofuel industry is a host of critical questions regarding its economic and environmental impacts, a complicated chain of influences that EBI researchers are trying to sort out. Illinois agricultural economist Madhu Khanna explained that the Institute's programs fall within four areas: land use, adoption and market impact of biofuels, laws and regulation, and life cycle analysis.

"There are three grand challenges for biofuels," she said. "First, to compete with food for land; second, to compete with crude oil as a fuel; and third, to be environmentally sustainable. So there are questions about the types of feedstocks, about the type of technology, about where government support should be provided, and about what policies are needed to support biofuels."

Not all biofuels are the same. Biofuels from crop residues and perennial grasses, such as switchgrass and Miscanthus, are considered more sustainable than corn ethanol. They have a milder carbon footprint and will have a smaller impact on food prices because they require less diversion of cropland from food production to fuels, according to Khanna.

Market forces will drive the costs, as will land and resource input prices, regulations, trade agreements, and fuel competitors. Greenhouse gas emissions, water quality, and biodiversity are also in the mix of factors that will determine the viability of biofuels. For that reason, Khanna said EBI is engaging in "a very interdisciplinary approach, with economists, soil scientists, atmospheric scientists, and engineers" working together "to determine the sustainable mix of biofuel feedstocks. Government policies are needed because the market left to itself will price all biofuels based on their energy content relative to gasoline and not value the different environmental benefits and energy security benefits they can provide."

These policies, however, may have unintended consequences. Biofuel policies like the Renewable Fuels Standard and tax credits for biofuels encourage a switch away from gasoline and towards biofuels, but do not create incentives for fuel conservation, Khanna explained. If gasoline supply is fairly responsive to price, these policies could lower the price of gasoline and create perverse incentives for increasing fuel use, reducing the extent to which biofuels displace gasoline and thus reducing their energy security and environmental benefits.

"Yields will be very important," she said. "There will be spatial differences in costs (based upon where and how the feedstocks are grown). There is not likely to be one winner (biofuel type), but more than one. Policies will be critical to determining what impact biofuels will have on food and fuel prices and on land use. Market effects can have a big impact on the environmental effects of biofuels—the market will determine how many gallons of biofuel will be consumed versus other fuels and therefore the overall reduction in greenhouse gas emissions."

PANEL: DAVID ZILBERMAN, UC BERKELEY; JAY KESAN, UNIVERSITY OF ILLINOIS

(From left) David Zilberman, Jay Kesan

One of the things David Zilberman and his team are considering is the influence that OPEC, the cartel of oil-producing nations, will have on biofuel prices. "OPEC tries to raise prices in the rest of the world but keep those in their own countries low," he said. "We need to develop a theory of how OPEC operates to understand how fuel prices are likely to be determined in the future with biofuels."

The price of energy is extremely flexible, he noted, and future biofuel pricing will be dependent on imports and exports of fuel, corn and oil costs, demand for foreign oil, and government mandates and standards. With this much volatility in the market, he said "the challenge is how to develop contracts that will provide fiscal viability to processors and growers."

The EBI groups will closely watch two policies that will impact the future of biofuels: the federal Renewable Fuels Standard, which requires 36 billion gallons of biofuel to be blended with gasoline by 2022, and the state Low Carbon Fuel Standard, which calls for a reduction of at least 10 percent in the carbon intensity of California's transportation fuels by 2020. EBI researchers will evaluate the impacts of these policies on the economics of the energy sector and the environment.

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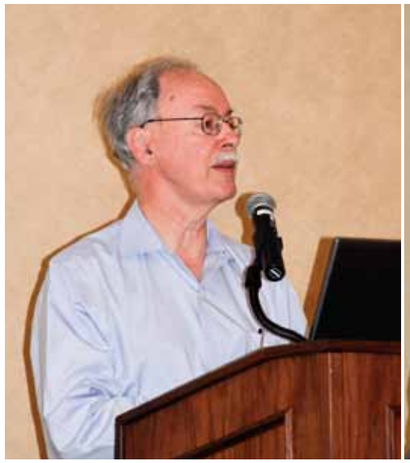
WHAT'S NEEDED: MORE COMMUNICATING, DATA MANAGEMENT, PRIORITIZATION



(From left) Chris Somerville, Steve Long, Paul Willems

Some common themes emerged when five focus groups gave retreat-concluding reports from their 90-minute brainstorming sessions. Virtually all of them expressed a desire for greater cross-disciplinary communications, both within the EBI and with outside groups. They professed the need for more and better data and the ability to archive it for inter-project uses. And they asked for Institute help in refining their efforts through prioritization of areas like preferred feedstocks, fuel type, and pre-treatment efforts.

Additional manipulation and visual tools and chemical analyses were also requested.

EBI Director Chris Somerville had convened the groups as a way "to look at where we have duplication and convert that into collaborations, to look at what the opportunities are that we're missing, where can we be combining our different components together, and what opportunities should be our priorities."

Participants selected their discussion group from among five topics: modeling, bioprospecting, bioconversion, economics-environment-policy, and "what's missing?"

Berkeley Lab's Norm Miller of the modeling group noted the significant number of programs in the EBI that are dependant on predictive modeling. The challenge for all, he noted, is the scarcity of data to provide a common set of inputs. Group chair and EBI Deputy Director Steve Long said that when they talked about the needs of the "downstream" process modelers, "the major issue was quality of the biomass. It varies by site and by year, but it will be important. Toughness of the material will determine the amount harvested. (Feedstock) yield and composition are important."

Miller added the consensus that the data should be recorded in one resource, accessible via the web site. The group also vowed to have teleconferences and some in-person meetings to maintain a tighter team during model evaluations.

The group prospecting for effective microbial organisms (co-chair Doug Clark of UC Berkeley called it "Fuels Gold") said its main focus will be on functional analysis of current samples, and expressed an interest in finding better lignocellulases from untapped natural sources.

"We need to reduce the complexity of the samples, establish standard assays and methods for determining and comparing activity, develop methods for high-throughput gene expression and activity assays, and better characterize the physiochemical properties of relevant feedstocks," Clark reported.

The group also encouraged greater efforts towards studying structural homology, perhaps through the use of new tools such as X-ray crystallography and Nuclear Magnetic Resonance (NMR) to narrow the targets of research.

UC Berkeley's Adam Arkin identified the bioconversion group's biggest collective need as the need to know which fuels molecules will be created and to really understand their issues, properties, regulatory challenges, co-products, and so forth. "We need to build our knowledge base in terms of chemicals, organisms and pathways of interest," he said. "We have to know where our edge is."

Somerville suggested they convene a workshop of experts to educate EBI researchers about making fuels, especially experts from industries that have been doing it for years. Possible chemical-biological hybrid processing approaches and the use of more exotic molecules are among the ideas the team will pursue.

The primary suggestions that emerged from the socioeconomic discussion group were program collaborations and contributions to the policy development process. Berkeley economist David Zilberman reported that the EBI can play an educational role in upcoming policy debates like the Low Carbon Fuel Standard, cap-and-trade programs, Renewable Fuel

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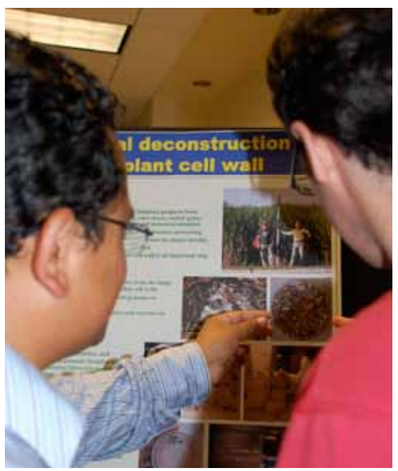
Standard 2, indirect land use impacts in EPA regulations, and carbon pricing.

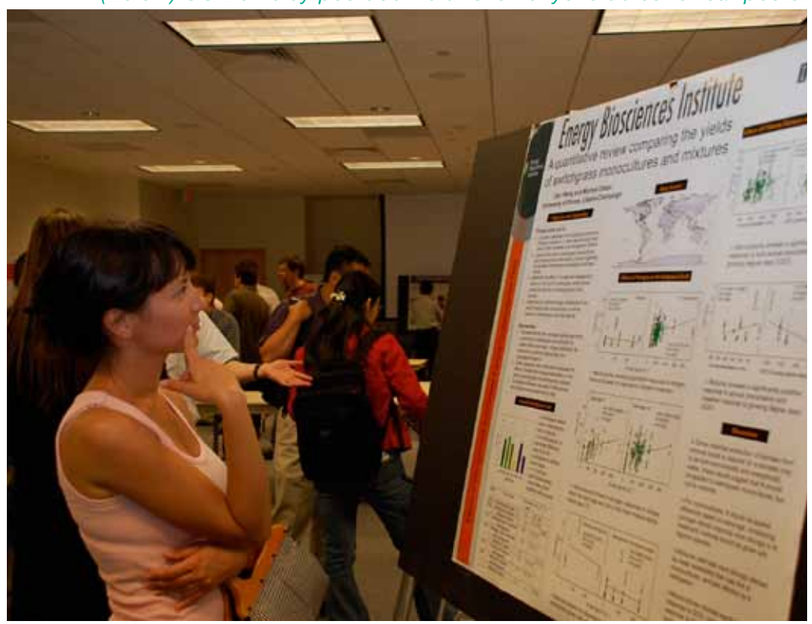
"Be strategic rather than reactive," EBI Associate Director Paul Willems told the group. And Somerville reminded them that researchers, while unable to advocate as EBI members, can comment freely in their roles as faculty members. "(The EBI) should produce good academic papers that policymakers can rely on," he said.

Berkeley Lab's Paul Adams and BP's Steve Pietsch summarized the dozens of suggestions made by the "what are we missing?" group and clustered them into four main categories: communications (intra-institutional and with outside groups, sharing of research results, videoconferencing of presentations, workshops); tools (analysis of things like pretreatment chemistry and plant composition); centralization (core capabilities like genetic sequencing, standardized biomass sample library); and new directions (chemical analysis of enzymes, international biomass transport issues, woody biomass deconstruction, hydrogen issues, and so on).

Recognizing the value of the focus group exercise, Somerville promised that a similar conference will be held annually as a learning and sharing opportunity. "We're not sure what the format will be next year," he told them, "but we need some joint thinking about what would be most useful for you."



(Below) UC Berkeley postdoc Heidi Szemenyei studies retreat poster



EBI SCIENTISTS, STUDENTS, STAFF USE RETREAT TO RECALIBRATE EFFORTS (CONT'D - FROM PAGE 1)

EBI conferees at the IHotel listen to Illinois' Carl Bernacchi discuss environmental impact modeling

Young Berkeley researchers enjoy barbecue dinner at the retreat – (around table, from left) Clarisa Bejar, Jerome Fox, Padma Gunda, Manuel Hoerl, Ian Wallace, Sarah Huffer, Jon Galazca, Heidi Szemenyei, Ying Gu

to formulate our future directions at the Institute."

And that it did, according to EBI Director Chris Somerville. At the closing session on Sunday, he reminded the attendees that "most of you by definition work in a narrow field of science, but the things you do collectively comprise the broad arena of what the EBI is set up to accomplish. It's important to understand the complexity of what we're trying to accomplish and understand that we are a lot more than the sum of the parts of the people in this room. It was important to give everyone exposure to what everyone else is doing."

Nearly 250 conferees—from Illinois, the campus and federal lab at Berkeley, and BP—participated in a program of thematic research briefings, farm and facility tours, and poster sessions. Sunday afternoon was devoted to five breakout focus groups that discussed what the EBI needs to advance its mission. A common and unifying theme of this discussion was the search for additional cross-disciplinary communications, which Somerville said was "music to our ears" and reflected the retreat's goal of enhancing interactions within the EBI.

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"When you think about resources—money, people, equipment," he told them, "you won't just think about the people you see every day, but about the people who were here. The Institute brings the resources and the capabilities, and we all need to get out of the box of traditional research and think about what's available through the EBI in general."

One of Long's opening slides was a cartoon depiction of the "golden spike" transcontinental railway ceremony, in which the converging sets of tracks were connected but misaligned. "We want to avoid this kind of situation (in the EBI)," he joked.

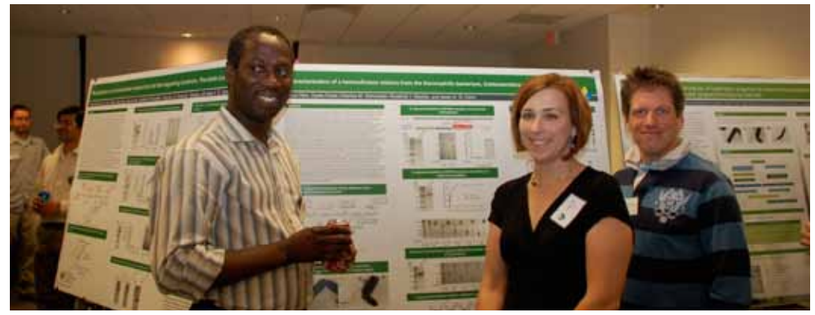
Then he instructed that individuals were prohibited from sitting next to people from their own institutions at subsequent lunches and dinners, a kind of enforced alignment that proved to be a popular socializing technique.

In his opening remarks, Somerville framed the importance of the EBI's task within the context of future energy demand: the world's energy use is predicted to nearly double by 2030, increasing a gigawatt every 1.6 days. "But where will it come from? And what will it do to our climate?" he asked.

The Institute, which is dedicated to studying the applications of biology to the energy sector, was established with certain principles in mind, he said: investing broadly across a complete spectrum of issues to create capability and a coherent view, supporting competing approaches to a problem, and identifying future opportunities as they arise. No other research organization of its type has the technical and thematic reach of the EBI, which handles 24 different topics in cellulosic fuels.

Somerville said the overriding goal of the EBI is "to create coherent knowledge in the field" by making discoveries and educating via interdisciplinary collaboration. The presence of BP, he noted, "gives us a real-world perspective, a greater understanding of the industry than any other academic group can attain." He said he felt "uniquely privileged" to work with BP and help them "make good choices, and help society make good choices."

He added, "We have a real chance to change the world."



Poster session visitors included (from left) Illinois researchers Isaac Cann and Angela Kent, and Joint Genome Institute's Matthias Hess

SOCIOECONOMICS: MAKING SURE BIOFUEL IMPACTS ON SOCIETY ARE POSITIVE (CONT'D - FROM PAGE 11)

Law professor Jay Kesan said his focus is "understanding the legal and regulatory environment and public policy issues that will result in an economically viable, sustainable biofuel industry." He described three approaches: looking at all regulatory requirements, from feedstock to consumer; analyzing and critiquing laws; and proposing solutions where gaps appear.

One of his team's efforts has been an empirical study of data from 166 ethanol plants in the period from 2000 to 2008, in which they found that through duration analysis, medium-sized plants have the greatest chance of continuing operation, compared to small-sized and large-sized plants. The team is also studying frameworks for sustainability and participating in efforts to shape standards for sustainable biofuels.

Their search will take them beyond the processing plant to issues such as carbon sequestration and the associated property rights, liability issues, and utilization agreements, according to Kesan. At the farm level, issues might involve carbon credits, cap-and-trade schemes, and so on. The legal infrastructure for biofuels is a work in progress at both the state and federal levels. EBI's legal experts will follow developments closely with a view to identifying topics where additional academic research would be useful in helping resolve emerging issues.

Instrumentation among the feedstock plots

THE PEOPLE BEHIND THE SCENES

Jenny Kokini

It is said that event management is a thankless task, the planners being acknowledged only if something goes wrong. Success is generally reflected by silence. A good meeting is one without complaint.

EBI Director Chris Somerville broke the silence. At the closing dinner on June 21, he expressed his appreciation for a flawless research gathering, crediting both the IHotel staff and the University of Illinois hosts for "a fantastic job." From the sumptuous meals to the endless administrative challenges that mark a conference of this magnitude, the retreat came off without a hitch.

In his champagne toast, Somerville cited EBI-Illinois Assistant Deputy Director Jenny Kokini for her overall management, assisted by Becky Heid and Connie Wilder, Illinois lab manager Rachel Shekkar, and communications specialists Melissa Edwards and Haley Ahlers. He also acknowledged farm manager Tim Mies and his helpers on the tour.

"They set a really high standard," he said. "It will be a challenge for us to replicate the success of the meeting next year in Berkeley."

EBI-Berkeley's Trisha Togonon, whose arrangements for getting nearly 120 people to and from Champaign on time were likewise flawless, is probably already thinking about 2010.

THE EBInsider

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