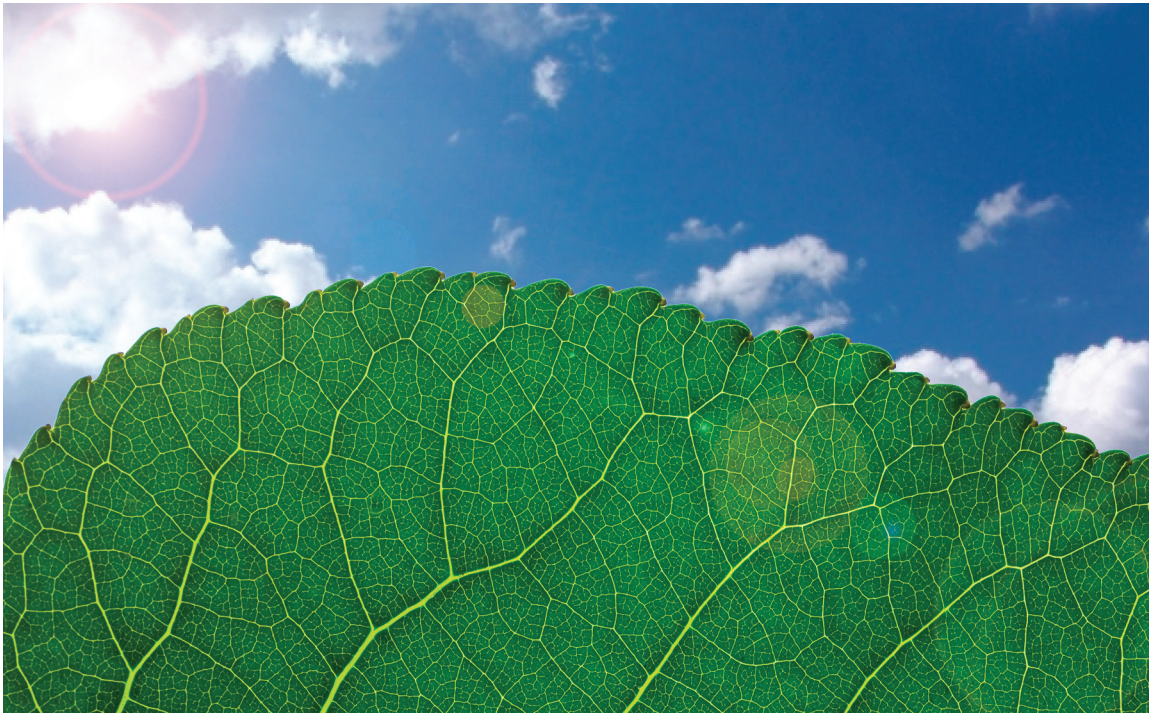


A Proposal to BP

Energy Biosciences Institute



University of California, Berkeley
Lawrence Berkeley National Laboratory
University of Illinois at Urbana-Champaign

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I. EXECUTIVE SUMMARY

INTRODUCTION

The University of California, Berkeley (UCB), the Lawrence Berkeley National Laboratory (LBNL), and the University of Illinois at Urbana-Champaign (UIUC) are honored to submit this proposal to partner with BP to create the Energy Biosciences Institute (EBI). Our three institutions share important core values and research philosophies, and we collectively offer unparalleled expertise and resources in the areas of alternative energy research and policy — all of which, we feel, strongly align with BP’s ambitious vision and hopes for the EBI.

We understand that the EBI is not to be *just another research institute*, but rather an extraordinary marshalling of human and infrastructure resources for the purpose of inventing and developing disruptive technologies that will address the energy needs of our global community. The Institute will assemble teams of scientists that will seek total-system solutions to the production of biofuels that are cost effective and carbon neutral. The EBI will create the next generation of scientists deeply knowledgeable in all areas of bioenergy and committed to the vision of the EBI, and will serve as a model for the type of large-scale academic-industry partnerships that will play an increasingly important role in solving the major global problems of the 21st century.

QUALIFICATIONS OF THE PARTNERSHIP — OVERVIEW

The qualifications that UCB, LBNL, and UIUC will collectively bring to the EBI include world-class research programs, facilities, and other resources in all of the areas relevant to the Institute’s initial and future priorities, from production of biofuels and related approaches to carbon-neutral energy, to biologically enhanced recovery and utilization of fossil fuels. All three institutions have a strong tradition in nurturing multidisciplinary initiatives, institutes, and projects; this multidisciplinary orientation enlivens not only science and engineering at the three campuses, but also the social sciences, humanities, and professions at UCB and UIUC. We also have a demonstrated tradition for reaching out and inviting collaborations with leading experts throughout the world that range from single investigator-driven initiatives to proactive recruitment of collaborations that can best utilize our extensive user facilities. The partnership also offers UCB’s and LBNL’s many connections with, and proximity to, California’s biotechnology ecosystem — the world’s largest — and UIUC’s many connections with its surrounding agricultural and agritech communities.

VISION FOR THE ENERGY BIOSCIENCES INSTITUTE

Character, Mission, and Goals. Our vision of the EBI is of a research community that harnesses the most creative science and innovative technologies to develop technically feasible and economically viable solutions to global energy challenges. No single scientific discipline will likely produce optimal technologies for the creation of biofuels, since each research area is likely to be constrained by boundary conditions determined outside of any specific discipline. Meeting this challenge requires a collaborative, multidisciplinary, and interactive research community.

The development of the atomic bomb at Los Alamos, the creation of high-energy physics “team science,” and the invention of the transistor at Bell Labs are striking examples of how large-scale problems were solved by establishing the proper multidisciplinary scientific culture. The success of the EBI will be greatly enhanced by a multidisciplinary facility housing researchers in chemistry, physics, materials sciences, genomics, and biology, working collectively in contiguous work space. Physical space constructed to house the EBI will be designed specifically to achieve an interactive research environment.

However, the foundation for great scientific and technical advances rests primarily on the creation of a social structure that promotes vibrant interpersonal interactions. This social culture was established in the 1930s at the University of California and the Radiation Laboratory (now LBNL) and continues today. The University's first Nobel laureate and founder of the "Rad Lab," Ernest O. Lawrence, was described by his colleague, Glenn Seaborg, who led the team of scientists that discovered 14 trans-uranic elements:

He had the vision to glimpse the limitless nature of the horizon and the generosity to make room for others. His personal credo was, "There is enough research for all of us to do." He interceded, with his rare persuasiveness, to create new facilities for worthy projects. He rejoiced as jubilantly in the success of those as in his own. As a result, the careers of many scientists, my own included, are founded on his large contribution and his generous nature. Indeed, so great was the opportunity he created that he was influential in the training of a significant portion of the present corps of nuclear scientists.

Overall, the EBI will be unified and propelled by a common purpose of working to solve a global problem of great magnitude and urgency, the excitement of performing pioneering research and utilizing innovative research methodologies, and expeditiously bringing transformative energy technologies to the marketplace. The core management structure of the EBI will be adapted from the research structures that existed at Los Alamos under the leadership of UC professor Robert Oppenheimer, at LBNL under Lawrence, and at Bell Laboratories during its heyday:

- Individual genius was nurtured, but those individuals were encouraged to quickly form teams of scientists when the rapid exploration of an idea required resources beyond the reach of a single principal investigator. Those collaborations easily transcended formal department and laboratory division structures.
- The scientific direction of those teams, as well as of the department and division leaders, was guided by the collective wisdom of each team, and "managed" by top scientists with intimate, expert knowledge.
- Collectively, the team decided which ideas to pursue and which paths to abandon or shelve. Bold approaches were encouraged and even demanded; failure was allowed, but there was an emphasis on recognizing failure quickly. Projects were subject to continuous, critical examination, and as soon as initial research revealed that a potential solution would not scale properly, the team moved on as quickly as possible to other opportunities.
- Department heads and division leaders were charged with keeping current with technical progress over as broad an institutional base as possible so that they could communicate relevant developments to bench scientists as they were happening.

This type of management structure remains in the DNA of UCB and LBNL. The influence of the scientific leadership that began with Lawrence can be seen in more recent UCB/LBNL history. A multidisciplinary team was formed by a scientist (in his mid-30s) that measured the cosmic microwave background anisotropy in the early 1990s; he has now been honored by the 2006 Nobel Prize in Physics. A discovery of equal magnitude, the measurement of the accelerating expansion of the universe, was the product of a multidisciplinary team effort and led by another Berkeley Lab scientist in his 30s.

The management style of Bell Labs is also deeply ingrained into the leadership of UCB and LBNL. The current chancellor of UCB, the current director of LBNL, the previous director of LBNL, and the current president of the University of California collectively spent their first 58 years as scientists and managers at Bell Laboratories.

Chris Somerville, director of the Carnegie Institution's Department of Plant Biology and a key part of the EBI team, has organized his program along similar principles.

Connecting Academic Research to Industry. The EBI will be a home to radical, open, exploratory research, while also remaining focused on those areas of science and technologies that have the most promise for transitioning into the marketplace. UCB's and LBNL's extensive relationships with California's world-leading biotechnology cluster will play an invaluable role. As an example, Jay Keasling's laboratory has demonstrated the quick transition from academic research on artemisinin, which showed that bacteria could synthesize this anti-malarial miracle drug, to the development of an industrial scale process through the founding of Amyris Biotechnologies.

BP's extensive research and technology expertise and business-industry leadership will strongly differentiate the EBI from other primarily academic research enterprises. This knowledge base will greatly enhance the Institute's potential to develop and bring to the world transformative energy technologies and train new scientists who can further connect academic and industrial research in bioenergy.

State-of-the-Art Facilities. The partnering institutions collectively offer a wide range of state-of-the-art and one-of-a-kind facilities that will enable the Institute to perform research at the highest level. These include a new Biomolecular Nanotechnology Center due to open in 2007 (UCB), the Central California 900-MHz NMR Spectrometer Facility (UCB), the Advanced Light Source synchrotron facility (LBNL), the Berkeley Center for Structural Biology (LBNL), the National Center for Electron Microscopy (LBNL), the Molecular Foundry nanoscience facility (LBNL), the National Energy Research Scientific Computing Center (LBNL), the Joint Genome Institute (JGI), the National Center for Supercomputing Applications (UIUC), the Institute for Genomic Biology (UIUC), the Integrated Bioprocessing Research Laboratory (UIUC), and the USDA National Maize Germplasm Collection and network of Agricultural Experimental Stations (UIUC), among others. (Note: the senior scientific leadership of LBNL, most of the associate lab directors, and the majority of division directors at LBNL are also active university faculty members at UCB.)

Organization of the Institute. At the highest level, the EBI will be divided into two components. The first will conduct open research and be staffed by UCB, LBNL, and UIUC researchers. The proprietary component of the EBI will conduct proprietary research and be staffed by BP scientists and engineers. This two-part structure, we feel, will comfortably accommodate both the collaborative needs of the Institute as a whole and the proprietary needs of BP.

At this time, we envision that the "open" component of the EBI will be organized into a total of six programs. The first four comprise the core scientific programs: Feedstock Development, Biomass Depolymerization, Biofuels Production, and Fossil Fuel Bioprocessing & Carbon Sequestration. A fifth program will focus on the social issues and economics of biofuels, and a sixth program, Discovery and Development Research Centers, will support all of the scientific divisions. These six divisions will serve as the formal structure to direct and coordinate the science carried out in approximately 25 EBI thematic laboratories.

The EBI thematic laboratories will be enabled to carry out basic and applied research in energy biosciences by significant direct financial support from the EBI. The creation of EBI research teams and projects will be as streamlined as possible, in keeping with the underlying culture of an institute that fosters the formation of self-assembling teams of EBI investigators and their groups who can easily reach out to other parts of the Institute, other parts of the partner institutions, and to the entire scientific community so that the very best talent can be recruited for a particular project. We propose a flexible, nimble structure of how to handle the formation of new EBI

projects with partner institutions or with new partners that minimizes the time and effort involved.

We envision that BP investigators will be located in an area of the EBI site that will allow a high degree of “flow” between personnel in the open and proprietary components of the EBI, but will also allow restriction of access as needed. However, we also expect that BP investigators will actively collaborate on open research questions with UCB, LBNL, and UIUC employees, students, and post-docs, and will have access to the research facilities, libraries, recreational facilities, and parking and transportation facilities of the partner institutions. The EBI’s director and deputy director will have confidentiality agreements with BP. UCB, LBNL, and UIUC all have extensive experience in successfully accommodating proprietary research activities, and we welcome their inclusion in the EBI.

Governance and Management. The Governance Board of the EBI will serve as the highest-level internal governing body of the Institute; it will reflect the shared governance structure of the EBI through high-level representation from BP, UCB, LBNL, and UIUC. In addition, there will be an Executive Committee, an Operations Committee, a Scientific Advisory Board, and Strategic Scientific Advisors. The EBI will be managed by a director who has been proposed to the Governance Board by BP in consultation with UCB, LBNL, and UIUC. The director, who has overall responsibility for the EBI, will be appointed by and report to the Governance Board. In addition, there will be an associate director employed by BP to oversee the proprietary research program and provide insights into business considerations, and a deputy director who will coordinate and represent the UIUC component of the EBI, participate in planning and management activities within the EBI, and report to the director. Investigators representing the various programs, an administrative director, a program, facilities, and safety director, and other EBI senior staff will round out the management team of the Institute.

Funding. Based on Model B presented by BP in the RFP, the open and proprietary components of the EBI will be funded from a BP subsidiary that will contract with the open and proprietary components separately. The four partners will impart direction and allocate financial resources to the EBI through their participation on the Governance Board. Funding allocated to the two EBI sites (Berkeley and Illinois), and to proprietary vs. non-proprietary activities within the EBI, will evolve with the work plan. Budgets and the corresponding objectives will be proposed annually to the Governance Board by the EBI director.

The EBI will provide for its own specialized management and administrative services but will obtain general facilities and administrative services from UCB. The EBI will pay the standard UCB on-campus overhead rate (52%) on all funds expended under the open research contract for work at the UCB site, and the standard UIUC on-campus rate (53%) for all work at that site. Work done by LBNL staff scientists will be subcontracted by UCB. Funds for activities at the EBI site at UIUC will be provided as an annual subcontract to UIUC based on a work plan developed by the EBI Executive Committee and approved by the Governing Board.

Staffing. We anticipate that the EBI director will hold a faculty appointment at UCB and a senior scientist position at LBNL. EBI investigators will be appointed from within the ranks of current UCB and UIUC faculty and LBNL scientists and supplemented through strategic recruitments from other institutions; they will be selected based on scientific expertise, creativity, breadth of knowledge in the field, and ability to communicate ideas. UCB and UIUC will collectively allocate at least 10 new tenure-line faculty appointments to support the development of the EBI. Prospective faculty members targeted for recruitment outside the partner institutions will be approved for faculty appointments through the existing practices in place at UCB, UIUC, and, where appropriate, LBNL.

In addition, the EBI investigators will strategically engage expert scientists as EBI collaborators. The

Institute will provide funding and EBI-access to the EBI collaborators to enable innovative research that is best carried out in these scientists' own laboratories. Each EBI collaborator will have a formally defined collaborative relationship with an EBI senior investigator, who will advise EBI management about financial needs and prospects for success of the collaboration in an ongoing way. Our goal will be to attract the best minds in the field to participate in the research program of the EBI.

Students who pursue graduate work at the EBI (at either UCB or UIUC) will receive an EBI appointment that will entitle them to access and use of facilities. The EBI will have the authority to recruit and appoint post-docs, technicians, and visiting scientists. All members of the EBI will have special appointments at the partner institutions that will enable use of libraries as well as parking, transportation, recreation, and other facilities. For example, members of the EBI in residence at UCB will have access to the University of California digital library, which includes an extensive online collection of scientific journals.

Communication between the UCB and UIUC sites will be facilitated by state-of-the-art video conferencing, real-time collaborative software, and frequent visits by both senior and junior scientists.

Intellectual Property. UCB, LBNL, and UIUC are confident that we can offer an approach to intellectual property issues that will provide full protection for BP's interests in this area as well as a process designed to minimize paperwork and review time, and expedite the successful bringing of new energy technologies to the marketplace.

We propose a unified approach to the granting of intellectual property rights arising from research that is fully funded by BP, and we have designated UCB as BP's single point of contact in order to implement our approach most efficiently. Specifically, we will commit to granting nonexclusive, royalty-free licenses in BP's areas of interest; such licenses will require diligence on the part of BP to commercialize the licensed invention and payment of a pro rata share of patent costs. We will also commit to granting exclusive license rights to BP in a manner that is consistent with full overhead-bearing corporate sponsorship of research. For example, BP will have a time-limited right to exercise a pre-defined option to obtain an exclusive commercial license, including, where feasible, capped fees and/or royalty rate ranges and successively renewed option periods. BP currently has a 10-year sponsored research agreement with UCB containing these features. In its first six years, this agreement has enabled a highly productive BP-UCB partnership and produced several patent portfolios to which BP has obtained rights.

Other Activities. Because of its location in the San Francisco Bay Area, where approximately 50,000 people are involved in biotechnology, the EBI will have a large audience who will want to access information and resources available at the Institute. We envision that the EBI will sponsor a regular series of symposia to inform both the public and the professional community about progress in the fields of interest to the EBI. Additionally, because of the high level of entrepreneurial activity in the region, the EBI will sponsor meetings directed specifically toward engaging the business community. We expect such meetings to expand the personal contacts between members of the EBI and the business community in ways that will create new scientific and business opportunities. UIUC will similarly engage the rapidly emerging biofuel feedstock and processing agribusiness community through a series of public and professional presentations, following the highly successful models that it has established with existing major agricultural markets.

Physical Space. The core UCB/LBNL senior investigators and BPI scientists will occupy contiguous space on the UCB campus. During approximately the first three years, the EBI will be located within newly renovated space in Hildebrand Hall and a renovated Calvin Hall. The combined space available in these buildings is approximately 35,000 square feet. At the end of that time, we propose, subject to environmental reviews and UC Regents approval, to locate all UCB/LBNL components of the EBI to a new building on the UCB campus. Funding of

approximately \$120 million has been pledged for this building. The building is proposed to be proximal to the state-of-the-art facilities at LBNL: the Molecular Foundry, the National Center for Electron Microscopy, and the Advanced Light Source. The EBI investigators at UIUC will co-locate on one floor of the new Institute of Genomic Biology building, which has been specifically engineered for integrative research. The core fieldwork from transgenic trials to testing of new biomass handling machinery will take place on the South Farms, immediately adjacent to the UIUC campus.

Our proposal provides a framework from which to begin discussion of the creation of this groundbreaking initiative. We look forward to working with BP in a highly interactive manner to create an innovative and exciting scientific program, team, and organizational structure that will enable BP's vision of establishing the EBI as the world's premier bioenergy research institute.

II. APPROACH

LEGAL STRUCTURE, GOVERNANCE, AND OVERSIGHT

If the EBI is to achieve its high potential, it must have legal, governance, and oversight structures that promote, nurture, and sustain the following: a rich intellectual environment that enables EBI researchers to practice fruitful mission-driven science; highly creative, collaborative, multidisciplinary projects; and flexibility that will allow the EBI to alter the direction of research projects as new opportunities emerge or internal or external conditions change. Mindful of these imperatives, we propose legal, governance, and oversight structures that preserve a crucial balance — simultaneously supporting a real-world orientation toward the development of marketable technologies, a commitment to visionary scientific endeavors, and a readiness to take advantage of the opportunities afforded by research serendipity.

We will work closely with BP to develop structures that preserve this balance — and thus support BP’s vision for the EBI — and also are consistent with UCB’s, LBNL’s, and UIUC’s principles.

Legal Structure

We propose working within the framework articulated by BP in Model B of the RFP (page 14). Our experience has demonstrated that this model works well in the academic environment to support productive university/industry collaborations focused on mission-oriented research. Figure 1 provides an overview of the proposed framework.

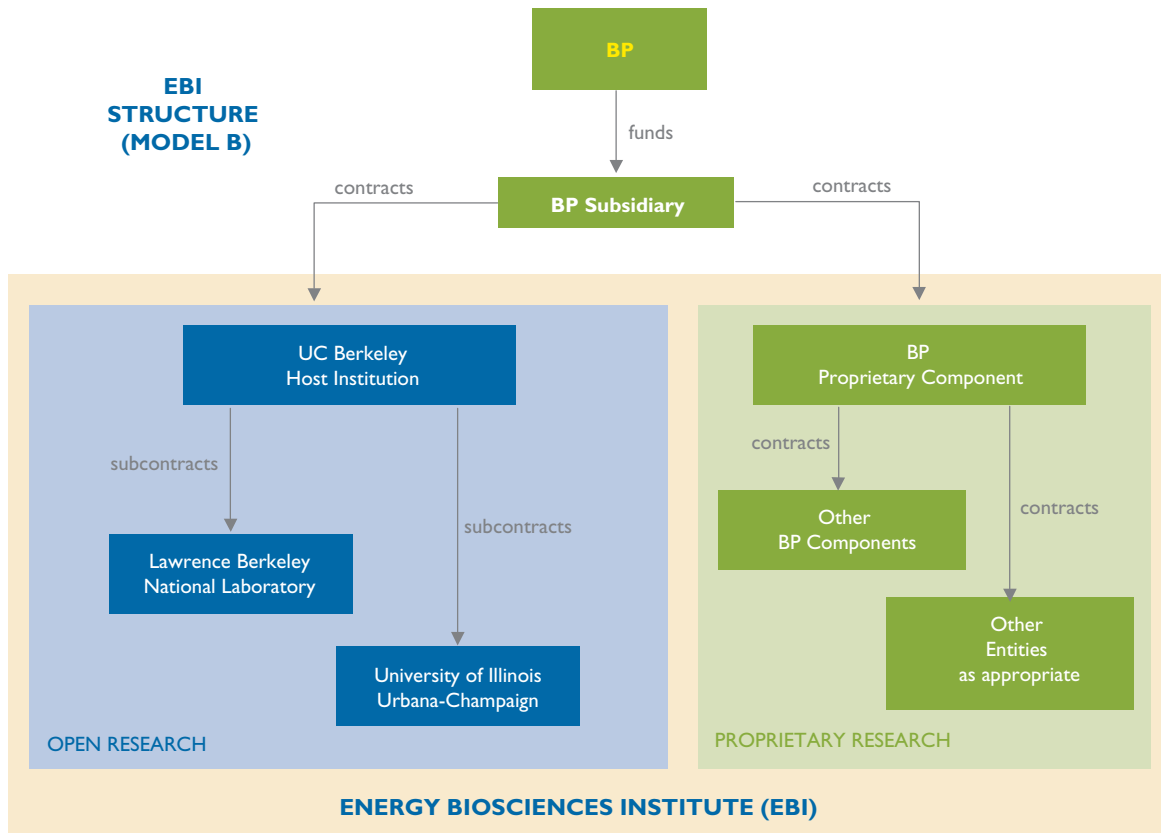


Figure 1

We envision that with the participation of LBNL and UIUC contract negotiators, UCB and BP will develop a single master agreement for the EBI under whose provisions all open research will be performed. This agreement will follow a model that has been used very successfully at UCB in the Intel Labet and in corporate master research agreements. UCB will then establish subcontracts with EBI partners and other collaborating institutions. All provisions of UCB’s master agreement will then flow down to collaborating institutions via the subcontracts. EBI proprietary research will be funded directly by BP or a BP subsidiary. We expect that virtually all technical capabilities needed for the execution of EBI research will be provided in-house or obtained on a fee-for-service basis, thus limiting the need for third-party agreements. Development of partnerships with third-party commercial entities will be considered jointly with BP following the establishment of the Institute, and joint negotiation of agreements pursued if necessary. UCB, LBNL, and UIUC currently have several successful university/industry partnerships in place that can serve as models in the event that additional partnerships are deemed desirable.

The open research component of the EBI will be governed by the EBI master agreement. Individual projects within the EBI program will be identified by a simple “Research Project Description” (RPD) that documents the project personnel, funding, duration, and scope of work. Each RPD will be signed by the participating institutional partners and will simply invoke the terms of the master agreement, obviating the need to negotiate or sign any new contracts. This RPD approach is a critical factor in providing the nimbleness and flexibility necessary for implementation of the EBI vision.

Governance and Oversight

We expect to work with BP to develop an EBI governance and organizational structure that will support optimal functioning and productivity at all levels and in all activities of the Institute. As a starting point for discussion, we propose the organizational structure illustrated in Figure 2.

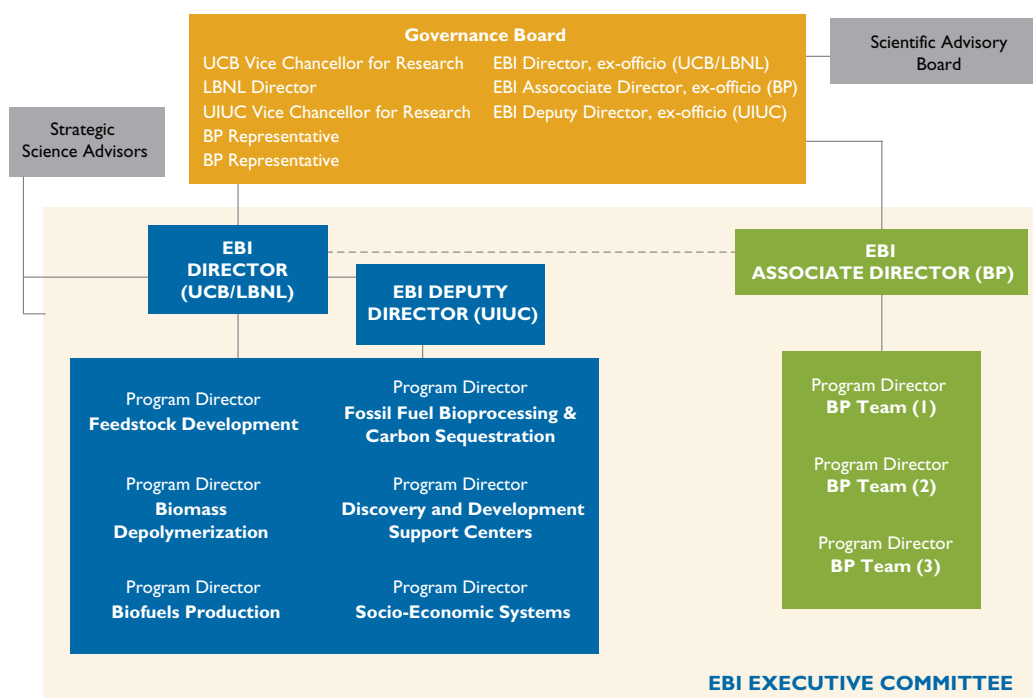


Figure 2

Within this organizational structure are the following governance, management, and advisory bodies: Governance Board, Executive Committee, Operations Committee, Scientific Advisory Board, and Strategic Scientific Advisors.

Governance Board (GB). The GB serves as the highest-level internal governing body of the EBI, reflecting the shared governance structure of the Institute with high-level representation from BP, UCB, LBNL, and UIUC. The EBI's director (UCB), associate director (BP), and deputy director (UIUC) will serve on the GB as ex-officio members. Final authority for the following areas will rest with the GB:

- Program review
- Budget allocation and oversight
- Space allocation
- Researcher affiliation
- Appointments of director, deputy director, and associate director

Executive Committee (EC). The EC includes the director, deputy director, associate director, and program directors. The EC is the hub for implementing the EBI vision and developing the work plan. It will convene twice a month and will be responsible for:

- Developing the EBI program and budget in support of the EBI vision for recommendation by the director to the GB
- Ensuring the coordination of efforts across programs, activities, and institutions
- Preparing EBI status reports
- Representing the EBI to the greater academic research and industry communities

Scientific Advisory Board (SAB). The SAB will provide the EBI with broad and strategic advice regarding vision, program implementation, and impact. The size, expertise represented, and terms of service of the SAB will be determined by the GB.

Strategic Science Advisors (SSAs). SSAs will be identified to provide targeted input regarding specific opportunities or challenges. SSAs will serve as a resource to the EBI leadership, including the director, associate director, deputy director, and program directors, as well as for researchers looking for input on specific projects or tackling specific challenges.

Operations Committee (OC) (Figure 3). The director, associate director, deputy director, and indicated senior operations staff will constitute the OC. The OC is charged with overseeing the management of day-to-day EBI operations; identifying and resolving operational issues; and coordinating inter-institutional operational solutions. This group of experienced, high-level academic and administrative managers will oversee all activities, ensuring that:

- Infrastructure support enables science to progress as planned
- Programs for education and outreach are developed and implemented
- Health and safety standards are met
- Intra- and inter-institutional communications strategies and technologies are optimized
- Records of program plans and Research Project Descriptions are meticulously maintained

The OC's role is to ensure that the administrative structure and institutional infrastructure optimally support the EBI's many facets. The OC will meet monthly to review progress and administrative issues and will provide the reporting lines for all staff.

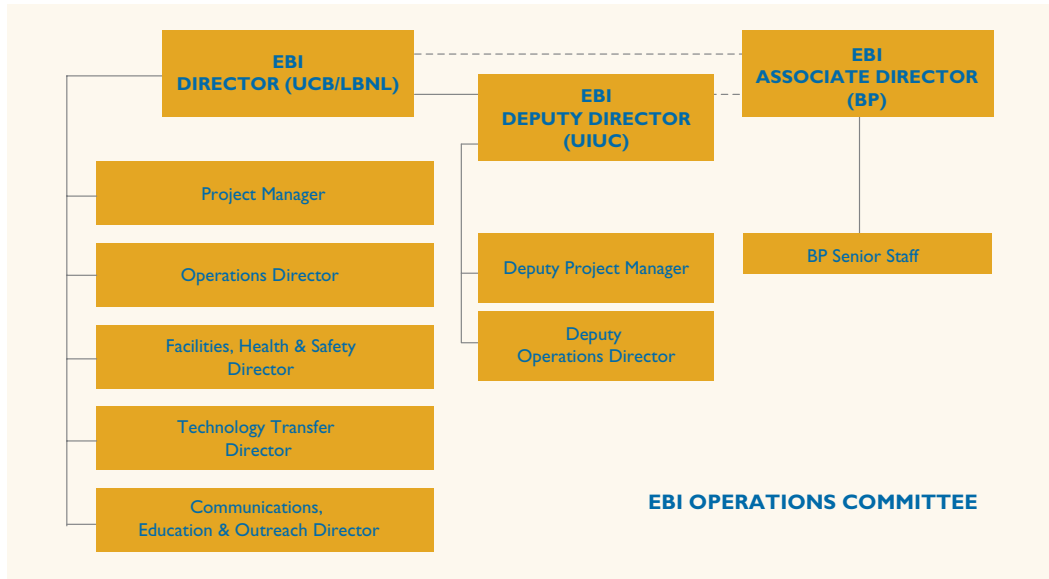


Figure 3

Roles and Accountability

Budget Planning and Oversight. The director will be responsible for working with the Executive Committee to develop the annual EBI program plan, with goals and milestones, and prepare the annual budget request for research and all Institute activities in the EBI open program. The director, associate director, and deputy director will work to ensure that the developed programs are closely coordinated and complementary across the Berkeley, Illinois, and proprietary sites. The program plan and budget request will be submitted by the director to the GB for review, revision, and final adoption. Realignment of funds greater than GB established limits will require review by the GB.

Funds will be set aside in the budget process for strategic opportunities. These will be controlled at specific organizational levels, including program director, director, deputy director, associate director, and GB. The GB will establish policies defining the funds available and control limits based on organizational levels for opportunity awards. The opportunity funds provide critical flexibility for leadership to take quick action in support of visionary and creative new research directions that arise from EBI activities and interactions. These opportunity funds will allow new research directions to be pursued in response to scientific need, directional changes, and serendipitous opportunities.

The director will be responsible for overseeing allocation to program directors and ensuring that expenditures are appropriate and allowable. The director will be responsible for shifting resources as necessary to meet milestones and goals within identified limits to be set by the GB. We suggest this limit might be in the 20% range. The deputy director will be responsible for overseeing allocations to UIUC program directors and overseeing

UIUC expenditures to ensure that all are appropriate and allowable. Program directors will oversee allocation of resources within their programs to EBI and collaborating scientists. Within limits established, program directors will have the ability to shift resources as necessary within programs to meet milestones and goals.

Space Oversight. Institutional commitments of space for the EBI are defined in “Buildings and Laboratory Facilities”. In the EBI space, the director and deputy director will recommend space allocation within the open research area for approval by the GB. The associate director will recommend space allocation within the proprietary area for approval by the GB. Proposed space allocation between open and proprietary space will be developed by the director and associate director and presented to the GB for final space allocation. BP will lease space allocated to proprietary research.

Appointment Oversight. The GB will have final authority over EBI researcher affiliations. The director, deputy director, and associate director will recommend researchers to the GB for affiliation. The deputy director, program directors, and program directors can recommend researchers for affiliation to the director, deputy director, and associate director.

It is envisioned that there will be two levels of affiliation defined by the GB: EBI investigators and EBI collaborators. EBI investigators will make a significant commitment to the EBI by playing a leadership role in the research program, participating in all EBI activities, and furthering the vision, mission, and goals of the EBI. EBI collaborators will be nominated by an EBI investigator to serve a specific role in a research project, and their appointment will be for a specified length of time.

When new faculty researchers are hired as EBI investigators and identified as joint EBI/institution appointments, recruitments will be conducted following existing policies and practices of the partner institutions, while the EBI affiliation will be approved by the GB. Hiring of senior operations staff and support positions will be the responsibility of the director, associate director, and deputy director, as appropriate, based on the location of the position.

EBI Management Oversight. The director and deputy director serve at the will of the GB. The GB will oversee the recruitment process, appoint both positions, review performance, and provide direction. The associate director will serve at the will of BP with joint oversight provided in partnership with the GB.

Research Agenda Oversight. The director, deputy director, and associate director will be responsible for working with the directors of each program through the Executive Committee to develop a comprehensive research program plan for review, revision, and adoption by the GB. The EBI’s progress will be evaluated regularly, and at several levels:

- Comprehensive annual review by the Governance Board
- Annual reviews of the EBI director, associate director, and deputy director
- Quarterly Executive Committee status reports
- Monthly Operations Committee status update meetings

The GB will conduct a comprehensive annual review of all EBI programs, including research, technology development and dissemination, education and training, communications, and management. The Institute’s annual report will be prepared and submitted by the director in collaboration with the EC for the open program, and by the associate director for the proprietary program. The annual report will include comprehensive status updates on all activities, as well as detailed plans and goals for the upcoming year.

The EBI director will be reviewed annually by the GB. Every three years, the director will be reviewed by an ad-hoc committee. The ad-hoc reviews will assess the director's effectiveness and will provide specific recommendations to the director and the GB to enhance program leadership and success. The deputy director will be reviewed by the GB on an annual basis. The review will assess the deputy director's effectiveness in his/her leadership role at UIUC and support of cross-institutional collaborative activities.

The Executive Committee (EC) will meet at least twice a month to review progress, identify issues that may require attention, and ensure the cross-fertilization of ideas and exploitation of the rich intellectual environment of the EBI. The EC will perform quarterly reviews where the program directors and senior operations staff will present progress reports on all projects and programs under their purview. These progress reports will serve as status reports and updates, and will identify problem areas and potential solutions. This process will foster a continued EBI mission-directed focus, ensure a high level of shared information among EBI leaders, and enhance progress towards milestones and goals, because issues will be identified and addressed early.

The Operations Committee (OC) will meet monthly to provide updates, identify operational issues, and coordinate efforts with respect to cross-cutting issues. We expect this group to convene more frequently on an as-needed basis in response to issues and needs.

Management Structure

UCB, LBNL, and UIUC have a solid record of developing and managing large-scale, mission-oriented research programs. Each has a demonstrated history of delivering results from these programs in a multidisciplinary research environment. Experience provides us with a solid foundation to understand, develop, and implement a program-management strategy that will coordinate efforts across traditional boundaries, support flexibility of research direction in order to quickly take advantage of opportunities provided by serendipity and the creative culture of the EBI — and achieve results.

Components of a research program include structured communication plans, multi-level assessment processes, flexible support structures, and a streamlined decision-making process. It is most important to develop support structures that ensure flexibility of research direction and coordination of efforts across traditional boundaries and that will identify and take advantage of unpredictable opportunities at every level of organization.

Research program management — which will include structured communication plans, multi-level assessment processes, flexible support structures, a streamlined decision-making process, and advanced videoconferencing capabilities — will occur at various levels of the organization. Components of EBI management will include:

- Milestones and goals that will be evaluated at the GB, Executive Committee, director, deputy director, associate director, and program director levels
- Regular strategy and update meetings between the director, associate director, and deputy director to ensure each program is supported and enhanced by the others
- EBI director-chaired monthly meetings of all program directors and lead investigators to provide opportunities to assess collaborative progress, address cross-program issues, and share needed expertise
- Revised and changed goals and milestones, and shifted directions, in response to advances, technology, and research results
- Monthly meetings of all scientists across all program areas
- Quarterly meetings with the GB to review proposed revisions and direction changes to the research plan based on research results and advances

- Program director–convened weekly meetings of EBI Investigators within their programs to ensure appropriate progress and revise goals to respond to advances, technology, and research results
- Program director–convened monthly super-group meetings of program researchers — including graduate students, postdoctoral fellows, staff scientists, and technicians — to validate current thinking about most-promising research directions and provide management of program decisions so that early indicators for termination and promising avenues can be pursued quickly
- Lead investigator–convened weekly group meetings of their project researchers — including graduate student researchers, postdoctoral researchers, staff scientists, and technicians — to serve the same purpose as the monthly super-group meetings but involving analysis at a higher level of detail

BUILDINGS AND LABORATORY FACILITIES

Overview

The University of California will host the Energy Biosciences Institute (EBI) within UC Regents land on the grounds of the Berkeley campus. EBI will be located in existing campus buildings for the first three years while the EBI headquarters, designed by the management team, are being completed. The headquarters will provide the Institute a premier showcase for its activities and events. It will be a hub of research and education activity, well integrated with all aspects of the campus. Planning for the new facility will be coordinated with EBI scientific program development to provide a collaborative, adaptable, and sustainable research environment. The facility will provide the Institute with a laboratory core, greenhouses, supporting utilities, parking, and other academic amenities. This facility will be in proximity to campus biotechnology research buildings and state-of-the-art, world-leading facilities for structural biology, nanoscience, genomics, electron microscopy, and supercomputing. At UIUC, the EBI will be located on a dedicated floor of the new Institute for Genomic Biology and will include space for proprietary research. In addition, UIUC offers extensive agricultural research facilities.

The EBI at UCB and LBNL — Preliminary Considerations

EBI Program Space Needs. UCB has near-term and long-term plans to host EBI in facilities that provide a holistic and integrated research setting for 150 EBI research and support staff. The actual workforce effort, staffing projections, and space distribution for the research functions will be based on strategic programming discussions with the EBI management team. The existing and new facilities will be open and flexible to enable exploratory research as advances are made and the research program evolves. The space will fully enable the development of thematic and common areas, which will include:

- Feedstock Development
- Biomass Depolymerization
- Biofuels Production
- Discovery and Development Support Centers
- Fossil Fuel Bioprocessing and Carbon Sequestration
- Socio-economic Systems
- Common meeting rooms, classroom area, student/faculty lounge, and administration

UCB is currently planning for the immediate availability of space that can, within the first year, provide a ramp-up to EBI needs starting in spring 2007. The identified facilities can readily be configured for open research and controlled access for proprietary research.

Proprietary Use of Facilities. UCB and LBNL have developed proprietary use agreements, and provisions for leasing space and enabling dedicated facilities for proprietary use. UCB and LBNL have extensive experience in creating and managing research facilities that accommodate both open and applied research. One campus model for proprietary research is the Intel Lablet, which facilitates Intel collaboration with UCB faculty members while providing for proprietary research, conducted in Intel-leased facilities. At LBNL, proprietary research can be conducted at the Joint Genome Institute, the Advanced Light Source, and other facilities. In all these

cases, the University of California units host proprietary research for sponsoring institutions in biotechnology and the semiconductor industry, under mutually beneficial negotiated frameworks, and impose physical control and intellectual property structures that enable both open and applied research. Examples of the Intel Lablet model, Cooperative Research and Development Agreements, and user facilities proprietary access agreements are provided in Appendix 2, p. 13.

Interim Space for the EBI at UCB

During the initial three-year transition period, 35,292 assignable square feet (asf) of laboratories and offices will be provided at existing buildings on the UCB campus. This transitional space will include a central building dedicated to the EBI (Calvin Laboratory, with 23,193 assignable square feet) and a complete floor of 12,099 asf in a nearby research building (Hildebrand Hall). From the very first days of program implementation, BP and EBI host research staff will be embedded within the campus research environment. This immersion will foster close collaboration and initiate a strong and productive research program with highly sustainable intellectual ties.

Calvin Hall is named after Melvin Calvin, who was awarded a Nobel Prize in Chemistry for unraveling the path of carbon in photosynthesis. Calvin planned this laboratory with an open design to enable an integrated multidisciplinary research program. The laboratories on each floor radiate outward from an open, central wet laboratory core, promoting communication and information-sharing. The upper floors will have controlled access so that BP confidential, proprietary work can be conducted, with secured information and research records. Entry to the facility will be through card readers to assure appropriate access controls. The space in Hildebrand is an entire, separate floor of newly renovated labs with controlled card-key access. More specific information about the interim facilities is provided in Appendix 3.1, p. 38.

UCB will extend the close ties and interaction created at the core Calvin and Hildebrand facilities by providing EBI research staff with full access to state-of-the-art facilities. UCB and LBNL already have some of the world's most advanced and productive protein structure, genome science, nanoscience, imaging, and computational research facilities. These facilities, described at the close of this section, are already being directed toward biofuels-related plant and microorganisms studies. These systems provide genomic and enzymatic characterization and engineering, and do not need to be further duplicated at the EBI site.

Permanent Space for the EBI at UCB: A New Dedicated Biofuels Facility

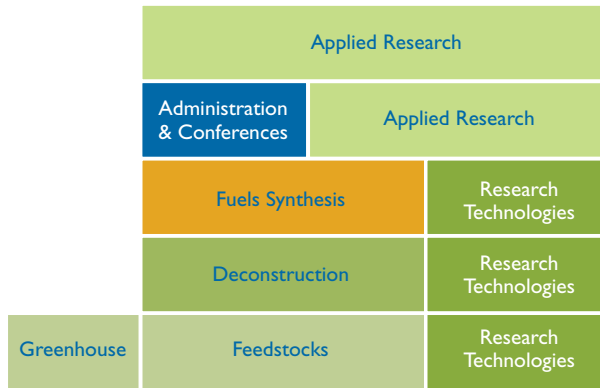
Overview of Features. Following the third year of the EBI's operation, UCB will provide 50,000 assignable square feet in a new, dedicated renewable fuels research building on the UCB campus that will be the EBI headquarters. EBI leadership will be closely involved in the conceptual design and layout of the facility, and the lead investigators will be closely involved in laboratory configuration, furniture, and equipment. This facility will have office and laboratory space for the 150 co-located Institute staff, including the EBI investigators, BP scientists, and laboratory personnel. Administrative space will be provided for the director, senior staff, and support staff.

The building will have space and amenities for a faculty/student social lounge and café; reading lounges; meeting and seminar rooms; classroom areas for coursework supporting the proposed designated emphasis; and staff support services. The configuration of these amenities will further contribute to a collegial and collaborative research environment. The building's relationship to the site will include ready access to greenhouses and parking lots adjacent to the facility. Specific designated areas will be provided for open and for applied research. The facility itself will have a modular structural configuration, and most of the laboratory spaces will be flexible to allow reprogramming as the EBI research program pursues the most promising opportunities.

The following functional representations provide an example of the conceptual layout of the facilities — probably as floors, but possibly as building wings as well:

The EBI building design will support and foster collaborative functional relationships. The space will be geared to support multidisciplinary teams and allow easy reconfiguration to meet changing directions and research needs. The initial facility concept is planned as a three-story structure, with floors and areas for open research and the specific areas of floors supplied with access controls for proprietary research. In all cases, the primary work spaces and the meeting spaces will be generally open and flexible to allow physical reconfiguration in real time. Built infrastructure such as plumbing, electrical, and data systems will be distributed on a modular basis and be accessible enough to allow for true plug-and-play capabilities. The data systems and Internet will be accessible to all work areas. Other building systems such as flooring, partitions, and ceilings will also support this flexibility. Offices, multipurpose meeting spaces, and other support spaces will be configured for an interactive work environment.

Building Diagram Functional Space Adjacencies



Site. The site for the EBI headquarters is largely open, 4,000 feet east of the science area of UCB and adjacent to nanoscience, chemical sciences, and materials sciences laboratories at LBNL. It is also in close proximity to the planned LBNL guest house (60 beds) and campus housing. The site is included in the 2006 LBNL Long-Range Development Plan (LRDP). Facilities in the area are designated to accommodate as much as a 216,000-gross-square-foot building as provided in the Draft Environmental Impact Report for the LRDP. A surface parking lot with capacity for up to 150 vehicles would fit adjacent to the building site. LBNL and UCB shuttle bus routes would be modified to connect the biofuels building to regional mass transit (BART) and downtown Berkeley amenities. The UCB Botanical Garden and Greenhouse are about 2,000 feet away, and the 3-acre growing field site is approximately a mile away.



Building Functional Spaces. In general, the EBI building’s research laboratories and their support spaces will be designed to operate as BioSafety Level 2 (BSL2) spaces. Specialty areas will include high-resolution imaging suites, cell culture laboratories, prefabricated cold rooms, and environmental rooms. Temperature and humidity conditions, air exchange rates, air pressure, and noise levels will be controlled to maintain a safe and high-quality working environment. The wet laboratories will be adaptable to a variety of functions without requiring costly or time-consuming renovations. An administrative suite will be located in an area with access to both open and applied research areas. Office space will be provided for permanent BP and EBI staff and for visiting scientists. A mix of private “closed office” and “open office” environments will accommodate different levels of assignment and security. The clustering of offices, the inclusion of larger shared laboratory spaces, and the strategic placement of the café will encourage collaboration among diverse EBI groups. Conference rooms will be distributed to allow for team meetings, and a larger conference/auditorium room will accommodate EBI events.

Safety and Environmental Leadership. The EBI construction project team will take an integrated design approach, resulting in a building with the least possible impact on occupants and the environment. With a goal of achieving the U.S. Green Building Council’s highest Leadership in Energy and Environmental Design (LEED) rating of Platinum, the EBI will showcase BP’s environmental commitment and leadership. The LEED Green Building Rating System™ is the leading benchmark for the design, construction, and operation of high-performance green buildings. LEED promotes a whole-building approach to sustainability by recognizing performance in five key areas of human and environmental health: sustainable site development, water savings, energy efficiency, materials selection, and indoor environmental quality.

The UC/EBI construction project management will choose consultants and contractors who are culturally aligned with the most stringent safety standards, as well as strongly qualified to perform their contractual obligations. The project will set a primary safety target of 0.2 per 100,000 “days away from work cases” (DAFWC), a five-fold improvement on the construction industry norm. Following occupancy of the building, operational safety will be emphasized, measured, supported, and continuously vectored toward best-in-class for research facilities.

Overall, during construction and afterward, the EBI will embrace BP’s HSSE aspirations — no accidents, no harm to people, and no damage to the environment. UCB has joined the California Climate Action Registry, pledging to measure, report and reduce greenhouse gas emissions as a means of mitigating climate change. To bring the campus closer to sustainability, UCB has interns working on projects to help the campus reduce carbon emissions. These projects include a pilot program to reduce energy use through education and behavior change; development of an “energy dashboard” for campus buildings; and a search for green chemicals that can be used by campus custodians. UCB was one of three recipients of the “Flex Your Power Award,” California’s top energy-efficiency award, for engaging faculty, staff, and students in its highly successful conservation efforts, which included creating the Green Building Research Center. Thanks to a number of actions taken, more than 10 million kilowatt hours and about \$1 million a year in power costs are saved annually on the UCB campus. The EBI will strive to operate in a manner that minimizes environmental impact. In addition to our goal of constructing a LEED Platinum building, we will incorporate environmentally friendly operating procedures, including chemical reuse and recycling programs, and participation in UCB’s campuswide climate-protection plan.

Health and safety is a core value for UC and LBNL that protects our most precious resource — our intellectual capital. Our approach is much like that of industry, in that we set aggressive targets and do our best to meet them. Also as in industry, safety is a responsibility of line management throughout the organization. The University of California is committed to achieving excellence in providing a healthy and safe working environment, and to supporting environmentally sound practices in the conduct of University activities. It is University policy to comply with all applicable health, safety, and environmental protection laws, regulations, and requirements. To meet this standard of excellence, the University implements management initiatives and best practices to systematically integrate health, safety, and environmental considerations, as well as sustainable use of natural resources, into all activities. All University activities are to be conducted in a manner that ensures the protection of students, faculty, staff, visitors, the public, property, and the environment.

The University’s goal is to prevent all workplace injuries and illnesses, environmental incidents, and property losses or damage. Achieving this goal is the responsibility of every member of the University community. Supervisors have particular responsibility for the activities of those people who report to them. The success of this approach is demonstrated by the recent performance of LBNL, which was in the top decile of R&D companies with 1,000 employees or more. And LBNL’s sustained performance has consistently been in the 75th percentile or better. Our combined expertise gives us the experience, ability, and infrastructure to create environmental health and safety standards and practices for the EBI that meet BP’s purposes and preserve the flexibility of an educational environment.

Construction Schedule. The biofuels building is scheduled to be approved by the Regents in March 2007, with detailed design development under way in the summer of 2007. The building site is included in the 2006 Long Range Development Plan (LRDP) for the area, and the environmental documents for a laboratory building at that location have been completed in draft for Regents approval in mid-2007. Financing for the project will be provided through the University, the State of California, and private sources. Groundbreaking will occur in 2008 with occupancy of the building by EBI in February 2010. Construction will employ a standard fast-track design-build process and a construction manager and general contractor contract. Following development of the design concept, initial construction packages will be released for the site utilities and foundations, followed by the structure and enclosure, the interiors and laboratory fixtures, and final finishes and equipment installation. The construction manager and general contractor will provide all the required services, including schedule management, cost management, estimates of probable construction cost, value engineering, constructability reviews, pre-bid and bidding management, safety management, and final installation of all conventional facilities.

EBI Integrated Research Space at UIUC

The deputy director of the EBI, leader of the Feedstock Division, UIUC EBI investigators, and key associate faculty will be located on the first floor of the new Institute of Genomic Biology (IGB). This will provide integrated wet-lab space, separate smaller laboratories with their own security access for the proprietary work of the BPI, and office space for all participants in a single, integrated work environment. Access to the EBI will be by key card. The area includes a dedicated conference room, meeting space, and its own break/lunch area.

Although the Open-air Feedstock Development Laboratory on the adjacent South Farms will be the major research facility for some participants, all will have their main office space within this one floor of the IGB. This space includes the following components:

Main Laboratory. The main laboratory has a total area of 6,748 gross square feet (gsf), which includes 4,492 gsf of lab space. This large lab is 126 feet long and has three double-sided, 24-foot-long lab benches and two single-sided, 24-foot-long lab benches. It also has eight 18-foot-long, double-sided lab benches with two six-foot movable tables at the ends of each bench. All of these lab benches and tables have epoxy tops with some epoxy shelving above. The benches have house gas, compressed air, vacuum, deionized water, H/C water at sinks, and power and data outlets.

Support Rooms. These support rooms, totaling 1,400 gsf, include two equipment rooms, three chemical fume hood alcoves, two controlled-temperature cold rooms, two tissue culture rooms with biosafety cabinets and CO₂ incubators (one with a prep lab), and one radioisotope room. These rooms may be allocated for the proprietary research of the BPI as needed.

Staff Work Stations. Adjacent to the large lab is a further 856 gsf of staff work stations. This area has 20 stations that include desks, tack surfaces, shelves, files, and a small four-person conference table.

Additional Support Rooms. These rooms, just outside of the lab and with corridor access, have a total area of approximately 1,080 gsf. They include one microscope room, one storage room, one dark room, one large equipment room, two controlled-temperature warm rooms, one dry lab, and one small equipment room.

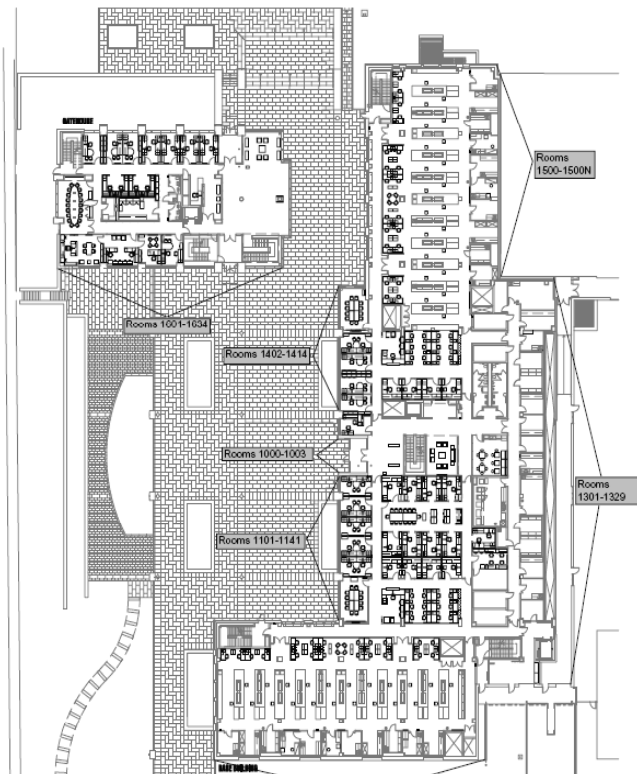
On the basement floor of the IGB, and directly accessible to the EBI space, is a series of large high-light controlled environment plant growth rooms with containment for transgenic plants and suitable for the growth of corn, Miscanthus, and switchgrass; and 4,879 gsf of office, administrative support, and conference space adjacent to space that includes five large, 160-gsf offices, 13 120-gsf offices, and two computer rooms of 180 gsf each, linked to a 294-gsf conference room. In the conference room, there is a 12-person conference table and data hookups for projection to a built-in LCD screen or teleconferencing equipment. Next to this is a conference/files area of 690 gsf and 1,175 gsf of administrative space that includes a large EBI administrative workstation and 12 additional staff workstations similar to those in the laboratory.



The first floor of the Institute of Genomic Biology (IGB) will house the UIUC components of the EBI. At the south end of the Quad, the building is in the heart of the campus — next to the Morrow Plots, and the University Library, the third largest academic library in the United States.

Institute for Genomic Biology
University of Illinois at Urbana-Champaign

First Floor



The 6,748 gsf main laboratory that will be shared by the EBI at UIUC, with access to potential secure proprietary space on the right.

Major On-Site Research Facilities at UCB, LBNL, and UIUC

UCB, LBNL, and UIUC have scientific infrastructure and instrumentation well-suited to addressing the most challenging tasks the EBI may undertake. These include dedicated biotechnology laboratories, specialized facilities for high-throughput structural biology and genomics analysis, highest-resolution imaging systems, supercomputers, extensive plant biology and greenhouse research areas, open-field experimentation space, and supporting research programs in carbon sequestration, petroleum discovery, and combustion research. Additional on-site research facilities are listed in Appendix 3.2, p. 42.

QB3 Central California Regional Nuclear Magnetic Resonance Facility (UCB). The heart of this important facility is the 900-MHz instrument, but the facility has several lower-field instruments (800 MHz, 600 MHz) that might be more appropriate for some needs. The 900-MHz instrument was purchased with funds provided by the NIH and is a multi-institutional resource that provides service to researchers at UCSF, UCD, LBNL, and Stanford.

QB3 Functional Genomics Core Facility (UCB). This facility will provide drop-off service in functional genomics, using Affymetrix Gene Chips. It will provide two levels of service:

- *Full chip service.* The facility will perform quality analysis of total RNA, cRNA synthesis, testing of labeling, hybridization, scanning, and data extraction.
- *Hybridization and scanning only.* The user will present the cRNA probe, labeled with biotin, and the facility will add the appropriate control oligos and cRNA, hybridize, wash, scan, and extract raw data.

QB3 Mass Spectrometry and Proteomics Core Facility (UCB). This facility provides mass spectroscopy service, both biological and small molecule. The facility operates a number of instruments, including:

- A 12-Tesla FT-ICR mass spectrometer
- A Tandem Time-of-Flight mass spectrometer
- A QTOF spectrometer
- A MALDI-TOF spectrometer
- An electrospray spectrometer for routine small-molecule work

Staff support includes a research-oriented mass spectroscopist who collaborates with other investigators on a variety of research projects. A Ph.D. mass spectroscopist manages the service aspects of the facility, operates the high-end instruments, and supervises technicians who operate the mass spectrometers for routine service.

QB3 Biomolecular Nanotechnology Center (BNC) (UCB). UCB has allocated 11,600 assignable square feet (asf) for a new shared research facility. The BNC will support the burgeoning interest at the intersection of nanotechnology and the biosciences, and will provide dedicated facilities and specialized equipment enabling research and education at the nano/bio interface. The BNC will enable handling and integration of proteins, nucleic acids, cells, and tissue samples, and the BNC will focus on the development of new advanced tools for quantitative biology and molecular diagnostics.

The BNC will support research in a number of thrust areas, including: biomedical diagnostics, systems nanobiology, biologic application specific integrated circuits (BASICS), nanophotonic probes for molecular imaging, soft-state biophysical devices, biodegradable polymer nanoengineering, nanoscale tissue engineering, neural interfaces & neural nanoelectronics, molecular engineering, and biomimetic nanoengineered materials and devices.

QB3 Facility for Protein Expression and Purification (MacroLab) (UCB). Structural biologists at Berkeley have attacked diverse problems associated with studying macromolecular machines. Individual groups have pioneered unique methods for purifying native complexes from cells, co-expressing complexes using recombinant DNA methods, and crystallizing complexes in small volumes. The MacroLab was created to develop and integrate methods to advance studies of macromolecular machines. By increasing the scale and speed of producing biochemical samples, scalable approaches will be established that will enable diverse efforts to image the fundamental assemblies of the cell.

Advanced Light Source (ALS) is the world's brightest soft x-ray synchrotron radiation source and a powerful source of hard x-rays for structural studies. Eight beamlines are dedicated to structural biology (see the Berkeley Center for Structural Biology, following). Three beamlines provide soft x-ray microscopy of biological materials and soft matter. Additional beamlines provide x-ray tomography and spectromicroscopy for detailed soils characterization. For the determination of biomolecular structures, the ALS is among the most prolific synchrotron facilities in the world. The ALS is also an outstanding source for studying molecular-scale phenomena of fuel systems, storage media, surface science, and electrochemistry. About 1,000 biological scientists use the ALS annually. Proprietary research is often conducted, on a cost recovery basis.

Berkeley Center for Structural Biology (BCSB) is a national user facility that provides access to and operates five protein crystallography beamlines at the Advanced Light Source (ALS). Since its inception, the BCSB has represented a strong partnership among industrial, academic, national laboratory, and non-profit researchers. These five beamlines have been uncommonly productive in terms of publication record, number of solved structures, and scientific merit and significance of work. A key component of three of the beamlines is the Automounter, developed at LBNL, which is an automated cryogenic crystal mounting/alignment system aimed at achieving high-throughput macromolecular crystallography by increasing experimental efficiency and reliability. It is ideal for screening large sets of crystals, for such purposes as optimizing protein design or understanding and engineering conformational changes in enzymatic processes.



LBNL Advanced Light Source — ALS



ALS Beamline Ring

UCB Oxford Tract Greenhouses and Growing Field (UCB). UCB has approximately 20,000 sf of research greenhouse space on a tract of land (the Oxford Tract) immediately adjacent to the northwest corner of campus. In this complex are greenhouses, insect houses, and a “head house” for preparation and analysis of plant materials. The Greenhouses are operated as a centralized facility by the College of Natural Resources. In addition, there is a one-acre, fenced, open growing field at the Oxford Tract. The campus also maintains four acres of growing space three miles from campus.

National Center for Electron Microscopy (NCEM) (LBNL). The NCEM is the largest electron microscopy center in the United States and houses instruments that are among the highest resolution (0.8 angstrom) in the world. NCEM’s seven specialized microscopes provide a basis for both high-resolution structural studies and spectroscopic characterization. NCEM is the lead U.S. facility for developing the Transmission Electron Aberration-Corrected Microscope, which will begin operating at NCEM in 2008 as the highest resolution microscope in the world (0.5 angstrom), making possible real-time dynamical studies at atomic/molecular resolution.

Molecular Foundry (LBNL). The Foundry is a national user facility dedicated to supporting research in nanoscience by providing users from academia, government, and industrial laboratories access to its state-of-the-art instruments, techniques, and expertise. Two of its areas of focus are especially germane to bioenergy: biological nanostructures, and organic and biomolecular synthesis. Its biological facilities enable molecular cloning, protein expression and purification, microbial and plant cell culture, and preparation and characterization of cellular components and products for construction of bio/inorganic assemblies. The facility offers recombinant overexpression of proteins and nucleic acids, genetic engineering of cell lines for materials integration, and protein engineering. Organic synthesis laboratories enable component synthesis, the development of assemblies of organic molecules and hybrid materials, and the characterization of polymers and molecular assemblies. A range of synthesis techniques includes organic, combinatorial, polymerization, and self-assembly. The Foundry houses peptide and oligonucleotide synthesizers, polymerization reactors, and instrumentation for purification and analysis of both small organic molecules and macromolecules.



The Molecular Foundry

Joint Genome Institute (JGI) (LBNL). LBNL manages the DOE Joint Genome Institute, which operates the Production Genomics Facility (PGF) in Walnut Creek, 12 miles east of LBNL. In 2007, JGI will add new space, including a 1,600-sf teaching laboratory. The PGF is among the world's most productive sequencing centers, accounting for about 25% of microbial genome projects worldwide, and now has a mission to sequence bioenergy-related genomes. The PGF has 106 capillary sequencing machines, 70 of which run 24 hours a day, seven days a week. Currently, on average, the PGF generates 3.1 billion bases of sequence per month, and 400 genomes have been sequenced or have sequencing underway, leading all other centers worldwide. A new 454 Life Sciences sequencer that runs 100 times faster than the previous generation of sequencers used by DOE JGI, uses a parallel-processing approach to whole-genome shotgun sequencing to produce more than 20 megabases (20,000,000 bases) of DNA sequence per 4.5-hour operating run. Further instrument upgrades are planned. The JGI has programs in informatics and computational genomics, genetic analysis, genomic technologies, genome biology, evolutionary biology, and microbial ecology.

National Energy Research Scientific Computing Center (NERSC) (LBNL). NERSC provides one of the most powerful open supercomputing environments in the United States. In the summer of 2007, NERSC will be delivering sustained performance of at least 16 trillion calculations per second — with a peak speed of 100 trillion calculations per second when running a suite of diverse scientific applications at scale. This newly acquired system will use thousands of AMD Opteron™ processors running tuned, lightweight operating system kernels and interfaced to Cray's unique SeaStar™ network. The system will be deployed to analyze extensive genomics and bioinformatics databases and simulate the most complex fluidics, chemical reaction, and biological systems. NERSC is planned to occupy a facility at LBNL in 2010.

Network of Experimental Farm Research and Education Centers (RECs) (UIUC). UIUC owns 21,077 acres of farmland throughout the state, and also has arrangements with landowners, farmers, and corporations to utilize many further acres for special purposes, including trials on particular soils, propagation, or isolation. The landholdings include six Research and Education Centers (RECs) spread throughout the state to cover a wide range of soil and climate zones across the 500-mile length of Illinois. The largest REC is the South Farms, which is contiguous with the UIUC campus, occupying more than 6,000 acres of farmland, with further holdings available for expansion. While most Midwest Land Grant Universities include RECs, the UIUC system is unusual in two respects. First, its main campus and REC are juxtaposed. Second, Illinois, by virtue of its north-south expanse, represents in its northernmost region the climates of many northern states, and in its southernmost region a climate closer to that of the southern U.S. states. Each REC has its own cultivation, planting and harvesting equipment, director, extension specialists, and full-time farm crews. The RECs are a service to crop producers, landowners, crop consultants, advisors, and the agricultural industry. The RECs form a system of field laboratories and classrooms accessible without charge to clientele who wish to obtain timely information on soil management and crop production practices applicable to the major soil resource areas of the state. They also provide locations for off-campus education. In addition, the RECs are field laboratories for proof-of-concept research conducted by UIUC faculty, and are equipped for contract proprietary research to support industry. Through cooperative agreements, UIUC has access to the land-grant REC network throughout the country, including locations in southern Florida, Hawaii, and Puerto Rico, which are used as winter nurseries.

Germplasm Collections (UIUC). The Maize Genetic Stock Center and the National Soybean Germplasm Collection are operated by USDA/ARS, located at UIUC, and integrated with the National Plant Germplasm System. UIUC also houses national plant pathogen collection centers. These resources serve the maize and soybean research communities by collecting, maintaining, and distributing seeds of maize and soybean genetic stocks, and germplasm as well; by providing information about the collection holdings through databases; and by providing molecular characterization. Each facility includes a full-time curator and technical staff for the maintenance and regeneration of stocks, as well as facilities for the holding of imported germplasm.

Plant Care Facility (UIUC). The Plant Care Facility (PCF) serves as the primary greenhouse space at UIUC available to faculty, staff, and students within the Departments of Crop Sciences (CPSC), Natural Resources and Environmental Sciences (NRES), and affiliated USDA projects; it is linked by an underground walkway to the EBI space. The facility is maintained and serviced by more than 20 full-time and part-time staff, who are directed by a facilities manager. The facilities are dedicated to the acquisition and dissemination of knowledge through research, teaching, and outreach activities.

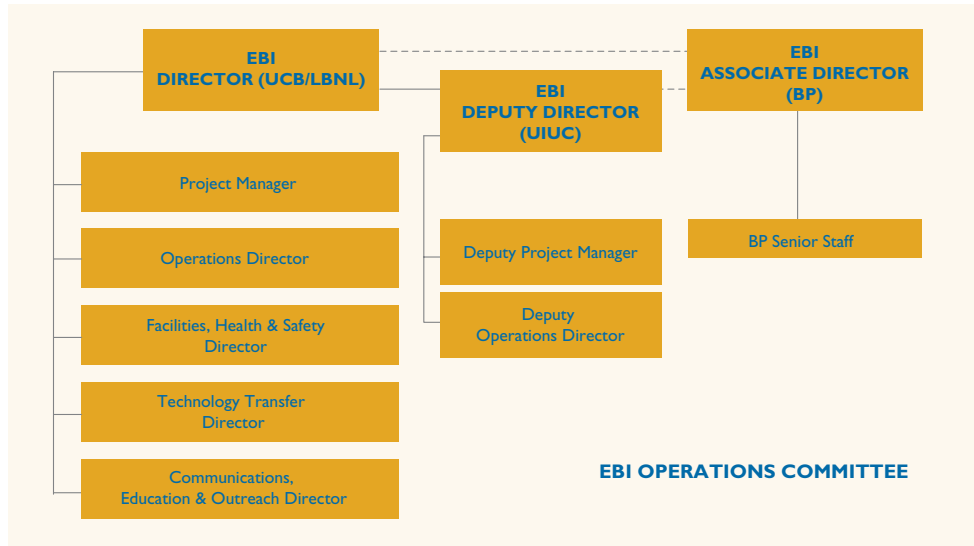
The facility includes 98,000 gsf of contiguous space under glass divided into more than 120 compartments of varying size and with independent climate controls and lighting; and plant growth bench space of 40,300 gsf, of which 33,000 gsf is BL1- and BL2-compliant for transgenic organisms.

Controlled Environment Plant Growth Chambers (UIUC). Environmentally controlled plant growth chambers are located in three centralized facilities totaling approximately 7,000 gsf of floor space. These spaces currently contain 85 individual units capable of temperature, light, and humidity control. Fourteen of these units can additionally control atmospheric levels of carbon dioxide or ozone, 12 are equipped to produce near-sunlight light irradiance levels, and two are specially equipped to operate at temperatures near freezing. All are BL1- or BL2-compliant.

National Soybean Research Center (UIUC). The National Soybean Research Center, a building built and equipped with federal and state funds at UIUC, has programs supported by industry, state, and federal dollars, as well as by gifts and grants. Housed within NSRC is a diverse association of research programs including entomology, plant pathology, breeding and genetics, food and nutritional sciences, and international marketing. Since 1993, NSRC's role has dynamically responded to the evolving technological and marketing conditions of the soybean industry. The NSRC's mission is to assist in expanding the scope, size, and profitability of the U.S. soybean industry. Research themes include: Enhancing Soy Productivity; Evaluating the Changing Commodity Market Channel; Expanding Feed Utilization; and Creating Food Uses. NSRC provides a model of integration of research, education, industrial collaboration, and producer and commodity group interaction that the UIUC would expect to emulate in developing the biofuel industry.

DIRECTOR AND SENIOR STAFF OF THE INSTITUTE

EBI Management Model/Administration



Director. The EBI director will direct all open activities in the institute, including research, communications, education, and outreach. It is expected that he/she will hold a faculty/scientist appointment at UCB and at LBNL. The director's salary will be based on his/her faculty appointment and paid from EBI funds administered by UCB. The EBI director, reporting directly to the Governance Board (GB), is responsible for implementation of research and education goals, administration of all programs, and fiscal oversight; will implement the long-term plans; and will be responsible for achievement of all EBI goals, including scientific objectives, milestones, and budget performance. In addition, the EBI director will:

- Provide the overall scientific vision and technical goals to the component programs;
- Be the public face of the EBI to the scientific community-at-large, governmental entities, industry/trade groups, and the media;
- Supervise the senior operations staff;
- Ensure an effective quality assurance program; and
- Oversee day-to-day operations.

A substantive review of the director will be performed annually by the GB. Every three years, the director will be reviewed by an ad-hoc committee to assess the director's effectiveness and provide specific recommendations to enhance program leadership and success.

EBI Deputy Director. It is critical to UIUC’s successful partnership that the responsibility for the collaboration and cross fertilization of programs and ideas is assigned to a scientist in a leadership position. The EBI deputy director will provide the management and oversight for all EBI activities at UIUC. He/she will be responsible for representing the UIUC in the management structure and will be responsible for coordinating the UIUC research, education, outreach, and communication activities at the UIUC site. The deputy director will be reviewed by the GB on an annual basis. The review will assess the deputy director’s effectiveness in his/her leadership role at UIUC and support of cross-institutional collaborative activities.

Conflict of Interest — Director and Deputy Director. The director and deputy director will receive confidential information from BP under the terms of one or more confidentiality agreements in order to understand BP’s business strategy, ongoing plans, and work in the proprietary side of the institute so that he/she can make informed decisions about potential technological developments and business alternatives. An authorized signatory from UCB or UIUC will sign such agreements, and the director/deputy director will co-sign an acknowledgment as having “read and understood” the agreement terms. The agreement will designate the director as the recipient of BP’s confidential information and will state that he/she has personal responsibility for safeguarding and managing the confidential information.

EBI Program Directors (PD). Investigators leading programs will be responsible for maintaining a thorough knowledge of the breadth and depth of the program area and interacting with the EBI leadership and other program directors to participate in advancing the mission of the EBI. The PD will ensure that all activities are coordinated across the program as well as with other programs, and that milestones and goals are met, revising plans and directions as needed. Annual program plans, status reports, and review materials will be developed by each PD, who will also represent his/her program in EBI activities.

Project Manager (PM). We propose the employment of a PM as crucial to the EBI’s management strategy. Under the direction of the EBI director, this individual will be responsible for overall technical management of the Institute, with broad-ranging abilities to organize, coordinate, and monitor programs to meet milestones and goals. The PM will monitor progress, milestone performance, and work plans. The incumbent will work with the director, deputy director, and program researchers to coordinate work within and among EBI component programs, reporting status regularly. The PM will work with the program directors to ensure status reports and annual plans are prepared, and will manage the process by which project changes — scope of work, budget, schedule — are requested and overseen. Additionally, he/she will work with the administrative director to implement communications systems and processes to ensure timely data release, science and technology information dissemination, and effective interaction among component programs. We anticipate that a parallel position (partial FTE) will be needed at UIUC to assist the deputy director with project management.

Operations Director (COO). Under the direction of the EBI director, this individual will be responsible for ensuring that business and operations support structures and resources provide a strong infrastructure for the EBI. He/she will manage all business services, resource allocations, and staffing levels; act as liaison for all operational functions with BP and collaborating institutions; and serve as the point of contact for coordinating any space and services that might be needed for the proprietary space (e.g., telephone, computer connections, custodial or repair services, etc). As with the project manager position, we anticipate that a parallel operations position at partial FTE will be needed at UIUC.

Facilities, Health, and Safety Director. Reflecting the importance of health and safety, the EBI will employ a professional responsible for managing all EBI facilities, and for ensuring developing a broad and comprehensive safety program with the highest level of safety protocol and procedure. The incumbent will develop the Building Emergency Response Plan; work with central EH&S departments to develop and implement the Injury and Illness Prevention Plan; monitor and enforce compliance with chemical hygiene plans, radiological use registrations, laser use authorizations, biohazard use authorizations, and toxic gas authorizations; and coordinate chemical inventory, laboratory self-inspection, maintenance of the Material Transfer Data Sheets (MSDS) library, quake-bracing, and fire prevention. He/she will be responsible for building-wide safety enforcement and compliance with local, state, university, and federal regulations; will enforce compliance in individual research labs, identifying hazards; establish safe working protocols; establish and chair the building's safety committee; and develop and provide a comprehensive safety training program. The individual will also work with researchers to develop protocols for special or unusual projects; conduct accident investigations, and make recommendations to avoid such accidents in the future; and maintain proper safety signage, including exiting signs in laboratories, corridors, and core facilities.

Technology Transfer Director. Under the direction of the EBI director and working with the EC, this position will work closely with the technology transfer offices for each partner institution and the appropriate staff at BP to develop and coordinate knowledge transfer and technology transfer activities, and any additional industrial involvement that the EBI decides to pursue. The incumbent will work to streamline intellectual property issues and will act as a liaison between researchers, industry partners, and campus technology transfer professionals. He/she will be responsible for helping to develop and maintain records of the Research Project Descriptions (RPDs) for each individual EBI-funded research project. The RPD documents the project personnel, funding, project duration, and project scope of work.

Communications, Education, and Outreach Director. Reporting to the EBI director and in consultation with the EC, this position will be responsible for development and implementation of EBI-related educational programs, including the development of graduate programs, activities, special symposia, and seminars. This will include identifying educational or teaching opportunities for the BP participating scientists, developing appropriate outreach programs, and coordinating or maximizing programs between the partner institutions. This individual will also be responsible for identifying technological and practical solutions to improve communications between the partner institutions, developing and maintaining internal and public websites for the Institute, creating brochures or other print vehicles, and working closely with public relations at the partner institutions and BP to showcase EBI activities. A primary responsibility of this position will be to ensure that the EBI is established in all sectors as the preeminent energy research institute.

STAFFING OF PRINCIPAL INVESTIGATORS, GRADUATE STUDENTS, AND POSTDOCTORAL FELLOWS

It is envisioned that faculty researchers affiliated with the EBI will carry joint appointments in their home department and the Institute and will make significant commitments to the Institute. This will enable them to participate in the EBI at a meaningful level, while still participating in teaching and academic life, and maintaining the remainder of their research program. We expect that up to half of the research support of each EBI investigator may be obtained from non-EBI sources. Specific graduate student and postdoctoral scholar participation in the research projects will be incorporated as appropriate on a project-by-project basis. Interaction with the EBI will encompass a broad mix of students and postdoctoral fellows through seminars and symposia, related courses that EBI/BP investigators might teach or participate in, or student programs. The area of energy biosciences not only poses exciting scientific challenges, but is compelling ethically and conceptually, and it is anticipated that there will be a very high demand on the part of faculty, students, and postdoctoral fellows to participate in research and programs sponsored by the Institute. These programs will generate close ties between the EBI, UCB, LBNL, and UIUC.

UCB and UIUC compete at an international level for the best graduate students in the world, and have top-ranked graduate programs across engineering and the sciences. The two institutions have similarly strong postdoctoral populations. Of the almost 1,100 post-docs at UCB and LBNL, 90% are in the sciences or engineering. As with the graduate student population, we attract the top postdoctoral fellows from around the world to work in our laboratories. Similarly, UIUC attracts the highest quality of researchers and currently employs 464 postdoctoral fellows, 89% in engineering and the sciences.

To identify and develop young researchers of great talent or promise into independent investigators, and to support basic multidisciplinary research and program development in the area of bioenergy, we propose to establish the EBI Distinguished Fellows Program. Our experience is that an extremely effective way to catalyze collaborative research is to fund fellows who will work on collaborative projects across EBI laboratories. EBI will offer three-year postdoctoral fellowships to brilliant young men and women who have received, or who are about to receive, the doctoral degree. The EBI Distinguished Fellows will interact with multiple research groups and play an important role in initiating collaborative projects at the boundaries of research areas and disciplines.

As noted above in the proposed legal structure, work funded through the open research component of the Institute will be consistent with graduate and postdoctoral training, and will not include publication restrictions other than a standard pre-publication review period by BP. During this review period, BP will be able to check that publications by graduate students and postdoctoral fellows do not include any inadvertently included confidential information belonging to BP, and/or to request (through UCB) that UCB, LBNL, and/or UIUC file a patent on certain subject matter prior to its public disclosure. If the EBI's proprietary research component wishes to further develop work that has been generated through open research, and needs specific faculty expertise to do so, a separate consultant agreement could be executed with the individual researcher to provide expertise and know-how.

RESEARCH PROGRAM

The organizing principles of the EBI research program are creativity, complementarity, flexibility, and collaboration. The program is organized around twenty-four “laboratories,” each of which represents an area of specialization relevant to solving the scientific and technical problems associated with large-scale production of biofuels, and with biological aspects of fossil fuel utilization and sequestration. Each laboratory will be led by one or more investigators who will develop an active research program described in the following sections. These lead investigators will also facilitate communication between research groups, institute best practices, and emphasize innovation. To broaden the intellectual and technical focus of the program, external collaborators will participate with the laboratories to develop complementary research programs. The mission of this *collaboratorium* will be to initiate and explore the most promising scientific opportunities in biomass conversion to fuels (Figure 1). The initial research objectives of EBI will thus continuously expand during the evolution of the EBI. This will ensure that EBI makes core discoveries in the field and secures corresponding patent positions, as well as providing insight into potential long-term problems that could impede development of a biofuels industry. A cadre of scientists within EBI focused on business applications will provide an appropriate mechanism for facilitating consolidation and commercial adaptation of discoveries as they emerge.

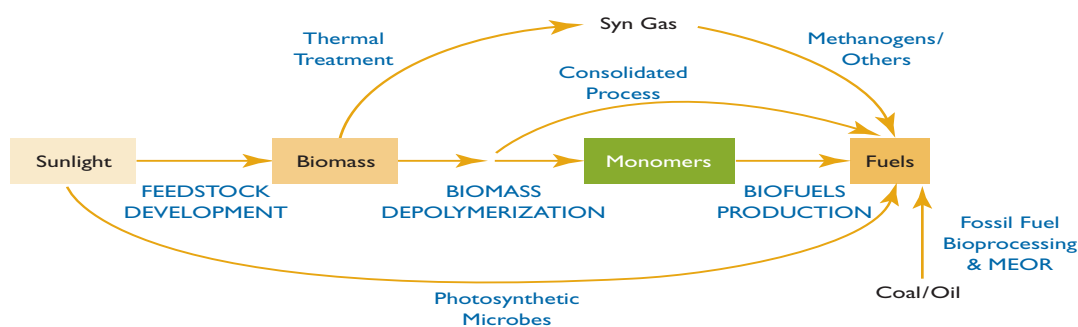


Figure 1 Routes of energy production to be explored in EBI. All caps indicate programs.

Although we view the research program as a single entity, it can be conceptually divided into several broad sub-areas or programs (see Figure 2). The modular nature of this structure allows us to quickly direct efforts to the most promising lines of research. For example, the “Feedstocks Development” program concerns the issues associated with ensuring that adequate supplies of plant biomass of optimal quality can be sustainably produced in close proximity to the lignocellulosic conversion plant (LCP) that will process biomass to fuels. We consider it likely that the first few LCPs will use corn stover as a feedstock, but that as high-yielding cultivars of dedicated energy crops, such as switchgrass, *Miscanthus*, and poplar, become available, these species will become the dominant feedstock sources. Therefore, the *Environmental Impact and Sustainability Assessment Laboratory* will broadly explore the long-term environmental consequences of the changes in land use that will accompany this development in order to ensure that the system is sustainable and environmentally benign. An important aspect of such studies will be a systems view of biofuel production that includes recycling of mineral nutrients from fermentation residues. The *Biotic Stress Laboratory* will also examine the potential threats to feedstock supplies posed by pests and pathogens, and will develop management practices that can control such problems when they arise. The *Feedstock Production Laboratory* will provide approaches for optimal productivity through field tests at many locations across North America and throughout the world. These experiments will be complementary to

experiments by the *Harvesting Transport and Storage Laboratory* concerning the development of farm machinery for harvesting, transporting, and storing biomass, and with logistical studies that will examine probable effects on regional infrastructure.

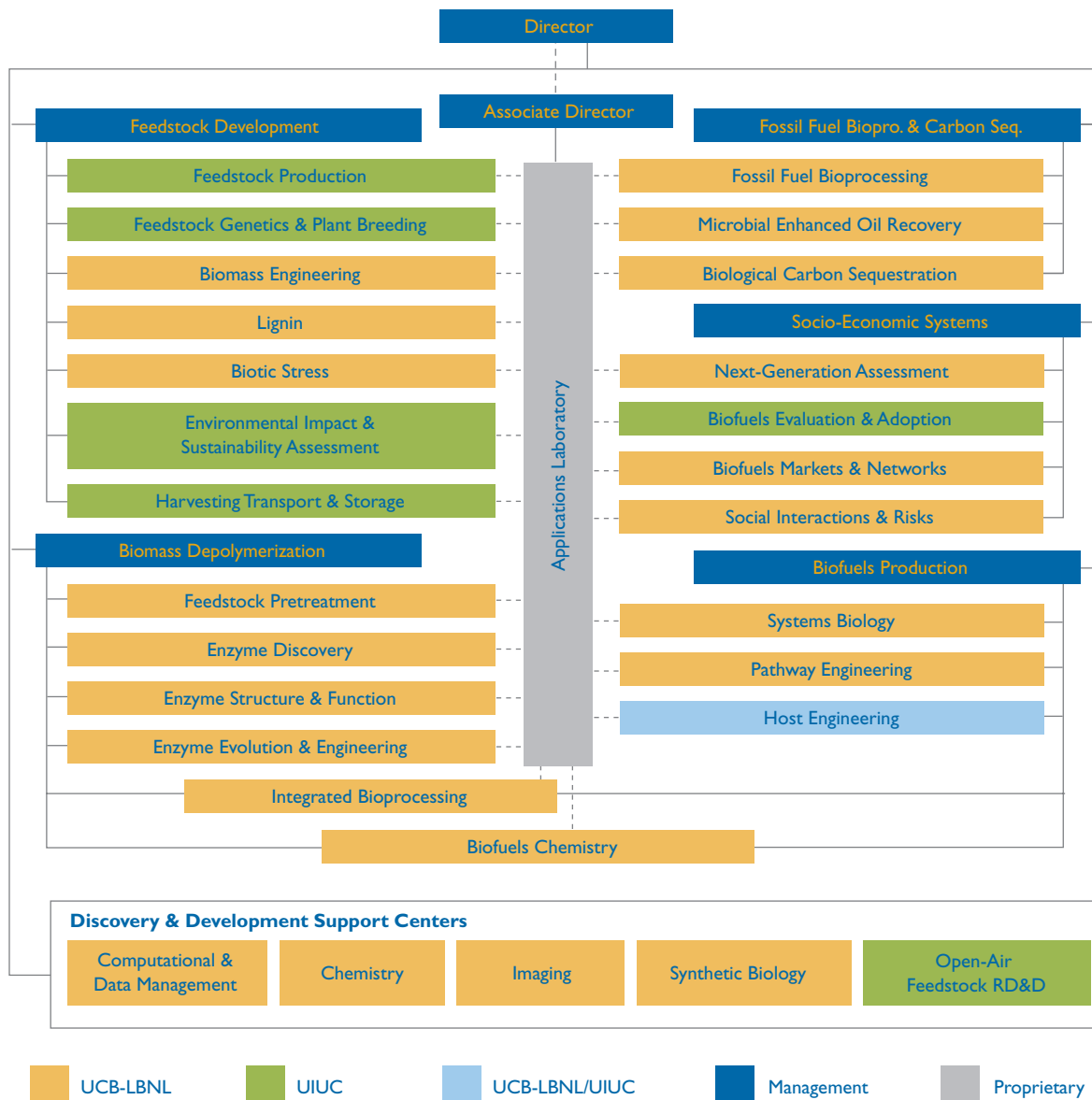


Figure 2 Research program and laboratory structure.

A second aspect of the Feedstocks Development program concerns fundamental investigations of how plant cell walls are synthesized and assembled. In particular, the *Biomass Engineering Laboratory* will use advanced tools in cell and molecular biology in combination with state-of-the art imaging and analytical tools to understand how cellulose and hemicellulose are deposited in cell walls, to identify key synthetic enzymes, and to explore the

degree to which the processes can be altered to yield cellulosic feedstocks that can be more easily converted to sugars and useful byproducts. Similarly, the *Lignin Laboratory* will explore the possibility of developing plants in which lignin can be easily removed and utilized as a feedstock for fuels or other purposes. The *Feedstock Genetics and Breeding Laboratory* will explore the extent to which natural variation in cell wall composition exists in the germplasm of energy crops and will provide complementary insights into the mechanistic studies of cell wall synthesis in regard to how variation in cell wall composition affects overall plant performance in field tests, and how variation in other processes affects wall composition. We consider it likely that optimized energy crops will carry several critical directed genetic changes and a large number of genes with relatively minor individual effects that have been selected from natural variation.

The second major program within EBI concerns issues associated with depolymerization of biomass to sugars and byproducts. Research efforts will address use of existing feedstocks as well as changing existing processes in response to genetically altered feedstocks. The *Feedstock Pretreatment Laboratory* will focus on using modern imaging and analytical methods to understand, at the molecular level, how the various pretreatment schemes that have been developed facilitate biomass depolymerization. These studies will facilitate the rational development of improved processes. The *Enzyme Discovery Laboratory* will exploit recent advances in high-throughput DNA sequencing to expand the range of polysaccharide and lignin-degrading enzymes from environments that have been poorly explored until now. An area of particular focus will be to understand how cellulosomes, complexes of hydrolytic enzymes and substrate binding domains, exhibit synergistic activity of natural substrates. This will underpin the development of new enzymes with enhanced cellulolytic activity. The *Enzyme Structure and Function Laboratory* will obtain molecular structures for important hydrolytic enzymes, including the structure of enzyme-substrate complexes, and will use such structural information to understand the mechanistic basis for substrate binding and regulation of activity. The *Enzyme Evolution and Engineering Laboratory* will combine information from structure-function studies with enzyme diversity studies to carry out protein evolution experiments designed to improve the activity profiles of useful hydrolytic enzymes for industrial-scale lignocellulose depolymerization. By contrast, the *Biofuels Chemistry Laboratory* will explore the possibility of using non-enzymatic (e.g., organometallic) catalysts to facilitate hydrolysis of certain substrates such as cellulose and lignin. In principle, an effective catalyst for glycoside hydrolysis could cause a fundamental technology shift in biomass processing. This laboratory will also evaluate new ideas for catalytic conversion of feedstock components directly to fuels. The *Laboratory for Integrated Bioprocessing* will explore the concept of using a single highly engineered microbe to produce hydrolytic enzymes and also carry out the conversion of biomass hydrolysis products to fuels. Although conceptually simple, achieving this goal is seen as very challenging because it will require integration of many aspects of the overall process.

The third major program will be focused on the conversion of lignocellulose hydrolysates to fuels and byproducts. This program has several related goals that include, in addition to developing systems that can convert all sugars to alcohol fuels, exploring the feasibility of producing fuels other than ethanol, developing organisms that are resistant to inhibitors (e.g., acetate, furfural, hydroxymethylfurfural) produced during depolymerization or to alcohols themselves, and developing organisms that are adapted to industrial fermentation conditions (e.g., salt, temperature). Thus, the *Pathway Engineering Laboratory* will identify the genes and corresponding enzymes and cofactors that catalyze the formation of feedstock-derived compounds into various fuels. Understanding how such pathways are controlled and how they integrate into the overall metabolism of the host organisms will be the focus of the *Systems Biology Laboratory*. Our goal will be to utilize the full suite of *-omics* tools to obtain whole-system data sets, and to develop computer models that can model the complex metabolic network in predictive ways that can be used to support pathway engineering for production of biofuels. Although we envision that certain well-adapted organisms such as *Saccharomyces cerevisiae* will continue to be of central importance in biofuels production, it is

apparent that other organisms will be important in producing biofuels other than ethanol.

The *Host Engineering Laboratory* will integrate knowledge from pathway and systems analysis into comprehensive understanding of the ancillary physiological changes that are necessary in microorganisms in order to adapt them to large-scale industrial use. These laboratories will seek to understand the balance between natural capabilities of organisms to withstand temperature, salt or solvent, the ability to take-up relevant compounds, the ability to grow anaerobically, or, in some cases, the ability to use light as an energy source.

The fourth major EBI program houses three laboratories that have “bioenergy” components but are not focused solely on the production of biofuels. The *Microbial Enhanced Oil Recovery Laboratory* will focus on investigating the use of microbial cultures to enhance recovery of petroleum from underground reserves. This laboratory will benefit from expertise within other EBI Laboratories related to the identification of novel microbes and their capabilities based on genome coding content. The *Fossil Fuel Bioprocessing Laboratory* will explore the possibility of using microbes for environmentally benign processing of coal to fuels. Although not well developed at present, we expect opportunity to develop rapidly because of the inevitability of large-scale coal use. The principal challenge is expected to be finding novel ways of converting coal to liquid fuels while minimizing CO₂ release. Finally, the *Biological Carbon Sequestration Laboratory* will explore ways in which biological processes can be managed or altered to increase the amount of stored carbon. This laboratory is expected to be very complementary to the *Environmental Impact and Sustainability Assessment Laboratory* and may benefit from the use of shared sites and personnel.

The Socio-Economic Systems Program will examine the economics of producing biofuels and the implications on society. The *Next-Generation Assessment Laboratory* will examine the social and environmental implications of biofuels and will make use of the best available tools and methods from life-cycle assessment, fuel-cycle analysis, computer-based systems analysis, cost estimation, multi-criteria decision-making, sustainability science, and environmental impact assessment. The *Biofuels Evaluation and Adoption Laboratory* will examine the information needs, policies, and incentives to enhance the adoption and strengthen acceptance of new biofuel technologies. The *Biofuels Markets and Networks Laboratory* will integrate and model the productivity, cost effectiveness, land use, environmental impacts, and transportation requirements of biofuels. Finally, the *Social Interactions and Risks Laboratory* will consider the design of institutions and policies to mitigate potential negative impacts of the adoption of biofuels.

The Research Laboratories will be broadly enabled by leading-edge resources that are uniquely available at the parent institutions and which have not previously been brought to bear on the challenges associated with production of biofuels. For example, the powerful analytical capabilities of the Advanced Light Source instruments and the capabilities of the associated scientists who work with the beamlines will provide completely novel analytical tools. The Joint Genome Institute, the largest non-health related sequencing facility in the US, has devoted and will continue to devote a large fraction of its sequencing capacity to energy-related organisms. The National Energy Research Supercomputer Center will provide computational capabilities for the analysis and redesign of biological systems. Similarly, the new Molecular Foundry and the Berkeley Center for Synthetic Biology are essentially unique. To ensure full use of these important facilities, the EBI will provide *Discovery and Development Support Centers* in which professionals with a high level of technical expertise will ensure access by all EBI participants to the technologies available at the parent institutions. These Centers will not duplicate instruments available at the parent institutions. Rather, the staff in the Centers will facilitate use of existing resources at the parents by performing specialized analyses or tasks, or by educating members of the EBI about how to use the technical resources that have steep learning curves.

The presence within EBI of a cadre of scientists (“BP investigators”) focused on proprietary research will provide an effective mechanism for facilitating consolidation and commercial adaptation of discoveries as they emerge. We envision that each of the BP investigators will be affiliated with one or more of the non-proprietary Laboratories and will contribute to the scientific discussions within those laboratories as well as to institute-wide discussions and workshops. Because the BP investigators will be more experienced than the postdocs, students, and technicians who are expected to carry out most of the research in the non-proprietary laboratories, the BP investigators will enrich the intellectual climate within the laboratories and will also bring knowledge of the biofuels industry to each laboratory. Thus, we envision that the BP investigators will play an important role in helping to focus the research program and in connecting the various laboratories to the overall mission of the EBI. Additionally, we envision that BP investigators may pursue research projects on the proprietary side of the EBI in the *Applications Laboratory*. The Associate Director will ensure that research projects carried out in the *Applications Laboratory* are complementary to research underway in the non-proprietary laboratories. A description of the management strategy for ensuring this outcome is presented below in the section describing the *Applications Laboratory*.

APPLICATIONS LABORATORY

Lead Investigator: *Associate Director of the EBI*

The Applications Laboratory will carry out the proprietary research program of the EBI. The mission of the laboratory will be to carry out research that is deemed sensitive because of competitive business reasons. Typically, research within this laboratory will originate in the conception of an invention. Because patent protection is frequently enhanced if an invention is reduced to practice, it can be useful to prevent public disclosure of an invention during the period in which the reduction to practice is underway. The Applications Laboratory will provide a private environment in which such reductions to practice can take place and in which discussions that may stimulate conceptions of inventions based on proprietary information may take place. Additionally, the laboratory may engage in research that is nearing application and which requires access to proprietary BP information or which is not of sufficient academic interest to be of interest to the other laboratories.

Two of the key objectives in managing the laboratory will be to ensure correct attribution of inventorship and collegial relationships with the non-proprietary laboratories. Although inventorship is defined in patent law, the participation of BP investigators in the non-proprietary intellectual life of the EBI raises special concerns and challenges. Inventions conceived during non-confidential discussions within EBI do not trigger any concerns. However, we envision that situations may arise in which a BP investigator conceives an invention during a confidential research discussion within one of the non-proprietary laboratories. Both the members of the laboratory and the parent institution may have a proprietary interest in the invention but may not qualify as inventors under the law. Furthermore, the information may arise from research not supported by BP funding and the members of the laboratory may wish to pursue open research that could undermine a solid patent filing. Although there is no formula for dealing with this and related situations, we believe that they can be managed by scrupulous attention to fairness. We envision that any inventions conceived as a direct result of confidential information will result in a meeting between the Associate Director (or designate), the BP investigator and the investigators who provided confidential information. The investigators will be informed that an invention has been conceived, they will be offered the opportunity to improve the invention based on their knowledge of the subject, and their cooperation will be sought in regard to delaying release of any sensitive information related to the invention during the period of reduction to practice. The minimal incentives for cooperation are collegiality in ensuring the success of the EBI and participation in any proceeds from the patent. Additional incentives such as increased funding for the project in question may also be possible.

We envision that scientists from the non-proprietary side of EBI will frequently conceive EBI-supported inventions. In some cases, at the discretion of the inventors and the Associate Director, the Applications Laboratory will pursue research to extend or reduce to practice such inventions. In other cases, the inventors may wish to further develop the invention within a non-proprietary laboratory according to standard practice at the parent institutions.

The research environment in the Applications Laboratory is expected to be similar in most respects to that of the other laboratories except that access will be restricted and information will not be publicly disclosed without permission from management. We envision that some BP investigators will have private interactions with other companies and will have access to non-BP proprietary information in addition to proprietary BP information and public EBI information. Thus, a significant effort will be invested in instructing the members of the Applications Laboratory how to manage information flow while, at the same time, broadly engaging in collegial interactions with other scientists.

Feedstock Development Program

The development of a biofuels industry depends upon the continuing availability of large amounts of inexpensive cellulosic biomass that can be obtained sustainably in relatively close proximity to conversion facilities. The wider Midwest, encompassing 200 Mha, possesses the climate and soils that allow high productivities under rain-fed conditions, and is the likely area for a large-scale biofuels industry in the United States. UIUC, being centrally located in the Midwest, will therefore lead the production, breeding, and farm machinery research and trials. UIUC has access to an extensive network of experimental farms across the region, and its extension service will link these developments to landowners and growers.

The Midwest region already produces nearly 180 Mt dry weight of corn stover annually. If only 10% of current Midwest land area is dedicated to crops such as *Miscanthus*, then there is the potential to provide an additional 1.2 Bt of cellulosic biomass. Assuming that 100 gal of ethanol may be produced from 1 t of cellulosic biomass, the region could produce 120 Bgal of ethanol, or its equivalent energy in other liquid fuels. Realizing this potential will require development of new agronomic procedures, new farm and processing machinery, and germplasm that is both adapted to varying soil and climatic conditions and is improved with respect to enzyme access to celluloses and hemicelluloses. Providing the means to realize this potential will be the primary objective of this program. Because of seasonality, procedures must also be developed to store the cellulosic biomass for up to a year with minimal degradation. Ideally, the biomass will have a chemical composition that maximizes recoverable chemical energy with minimal processing costs.

Overall, the mission of this program is to increase the quantity and quality of feedstock arriving at the processing plant, while increasing the efficiency of resource use in production. The foci of the following laboratories are based on a systems overview of the major limitations, from germplasm to feedstock storage, that must be solved to achieve the mission.

We envision that corn stover may be an important component of the cellulosic biomass supply during the initial phase of industry development, but that the use of stover will give way to perennial grasses such as switchgrass and *Miscanthus* and woody species such as poplar, as these species are adapted for use as dedicated energy crops. Particular emphasis will be placed on *Miscanthus* because of the exceptional biomass yields it has shown in early US trials conducted by UIUC (up to 60 t/ha and more than double switchgrass). These impressive yields are obtained with minimal external inputs, suggesting *Miscanthus* production systems could represent a disruptive technology for feedstock supply (www.Miscanthus.uiuc.edu). The research programs in the EBI

Feedstock Development Program are designed to address basic research and technological foundations allowing the development of improved feedstocks and the applied management practices associated with growing, harvesting, and storing the feedstocks.

FEEDSTOCK PRODUCTION LABORATORY (UIUC)

Lead Investigator (I): *Stephen Long (UIUC)*

Collaborators: *German Bollero (UIUC), Michael Gray (UIUC), Emerson Nafziger (UIUC), John Vogel (USDA, Albany), Tom Voigt (UIUC), Ben Tracy (UIUC)*

Recently, the USDA and DOE produced an analysis of where the feedstocks for a bioenergy industry can be obtained. This document proposed that a majority of the feedstock would be derived from crop residues, but that a significant proportion would be obtained from dedicated energy crops. We believe that the EBI should be agnostic about the relative contribution of dedicated energy crops vs. crop residues, and must have expertise in subjects that cover both.

Because crop residues are derived from commercial varieties of crops, the EBI will usually find it most practical to collaborate with commercial seed companies by contributing expertise and technological developments that are not available to the commercial entities. We anticipate that corn stover will be the largest single and most uniform initial source, and will therefore be our initial focus. In many cases, this collaboration may take place on the proprietary side of the EBI.

Through dedicated multi-location agronomic studies of current commercial maize germplasm, we will investigate two major questions regarding the production of corn stover as an energy feedstock. First, we will compare the effects of complete, partial, and no removal (current practice) of corn stover on subsequent yields. Second, we will study the influence of reduced amounts of supplemental fertilizer, particularly nitrogen, in order to optimize the energy balance for stover production and quality.

In contrast to corn, since relatively little research has been carried out on dedicated energy crops, the EBI is expected to greatly impact the development of these crops. Areas that need significant investment include integrated basic and applied studies of efficient methods for producing high yields of quality uniform biomass. Agronomic questions include issues such as how to establish the crops; when to rotate; fertilizer requirements; recycling of minerals from fermentation sludge, weed, pathogen, and pest control; fire control; and many related factors. In some cases, it will also be important to assess the potential invasiveness of potential energy crops. We will use and extend the large-scale fields of *Miscanthus* and switchgrass established on the proposed site of the UIUC Open-Air Feedstock RD&D Center for testing different management, herbicide, and fertilizer trials. These will also serve as the testbed for farm equipment development and initial source of material for enzyme and microbial processing. Through the Land-Grant Experimental Station network, trials will be extended to a broad range of US locations.



A single year's production of shoots by *Miscanthus*. These first agricultural trials of *Miscanthus* in the U.S. were conducted at UIUC. Yield = 60 dry tons per hectare in 2004.

FEEDSTOCK GENETICS AND PLANT BREEDING LABORATORY

Lead Investigator (I): Stephen Moose (UIUC)

Collaborators: New Recruitment - perennial grass breeder (UIUC), New Recruitment - perennial grass genomocist (UIUC), Martin Bohn (UIUC), Robert Fisher (UCB), Mike Freeling (UCB), Matthew Hudson (UIUC), Jack Juvik (UIUC), Steve Long (UIUC), Torbert Rocheford (UIUC), Dan Rokshar (UCB/LBNL), Marty Sachs (USDA), Christian Tobias (USDA), John Vogel (USDA), Jack Widholm (UIUC)

Companies are best positioned to produce seed and propagules at commercial scale. Thus, we envision that breeding of energy crops will be carried out by companies and that the proprietary side of EBI will have collaborative relationships with these companies. In support of these collaborations, EBI will coordinate germplasm evaluations for energy crops. An initial target will be commercial and experimental maize germplasm, which will be characterized for phenotypic variation in corn stover productivity and the efficiency of stover conversion to cellulosic ethanol.

All *Miscanthus* so far grown in the US is a clone of a single sterile hybrid. Since *Miscanthus* is the newest yet most promising of the dedicated biomass crops, it will be critical to establish a full germplasm collection of this broadly occurring complex. This collection will provide a basis for producing cultivars adapted to different parts of the US and to identify fertile lines of equivalent agronomic potential as the hybrid. The UIUC campus already houses genetic stock centers for maize and soybean within the US National Genetic Resources Program, and we will use these models to develop a similar collection and characterization of *Miscanthus* germplasm within the EBI. This will be closely integrated with sequencing of *Miscanthus* by Joint Genome Institute (JGI).

The Feedstock Genetics and Plant Breeding Laboratory will focus on associating genetic variation in maize, switchgrass, *Miscanthus*, and poplar with traits relevant to the productivity and fermentation quality of these crops. These include photosynthesis, cell wall composition, winter survival (for perennials), nutrient remobilization, disease resistance, and abiotic stress tolerance. This information will aid in adapting bioenergy crops to diverse production environments, even within the Midwest. Because the perennial grasses may exhibit sterility or self-incompatibility, it will also be necessary to investigate the genetic mechanisms controlling flowering, self-incompatibility, and other issues related to propagation technologies. As has been achieved in many

other crops, modifications to these reproductive traits will likely enable dramatic productivity increases via hybrid vigor and the crossing of parental lines with complementary phenotypes.

The program will also address knowledge gaps that currently limit the effectiveness of breeding approaches for *Miscanthus* and switchgrass improvement. These include characterizations of genome structure and genetic diversity, the construction of high-density genetic maps for marker-assisted breeding, and development of genetic transformation technologies. Genomics information from close relatives of bioenergy crops, particularly sugarcane for *Miscanthus*, will be leveraged extensively. Because of the advanced tools available for maize functional genomics, maize will be used as a testing ground for improving the perennial grasses. Additionally, as knowledge of the genetic basis of bioenergy traits improves, the development of biotechnology tools for transgene delivery, expression control, and functional testing will be required to create and evaluate novel genetic variation for improving biomass yield and quality. Examples include the introduction of herbicide resistance in the perennial grasses to aid establishment, improved fall translocation of nutrients to the root system, and increased phenolic and lignin content in roots to slow decomposition and so increase carbon sequestration.

To support both characterization of extant and created germplasm, and the Biomass Engineering Laboratory, a high-throughput biomass quality analysis facility will be established in the EBI space at UIUC. Near Infrared Spectroscopy (NIR) will be used to quantify cell wall constituents such as cellulose, lignin, sugars derived from hemicellulose, proteins, and structural inorganic compounds. This technology will facilitate establishment of associations between cell wall composition and fermentability of the hydrolysates. In addition, hydroxycinnamic acids, ferulic acid (FA), *p*-coumaric acids (PCA), and other digestion/fermentation inhibitors will be quantified using High Performance Liquid Chromatography (HPLC).

BIOMASS ENGINEERING LABORATORY

Lead Investigators (2): *Chris Somerville (LBNL), and New Recruitment (UCB/LBNL)*

Collaborators: *Paul Adams (LBNL), Manfred Auer (LBNL), Ken Keegstra (Michigan State), Peggy Lemaux (UCB), Eva Nogales (UCB/LBNL), Marcus Pauly (Michigan State), Henrik Scheller (Copenhagen)*

The main constituents of biomass are polysaccharides such as cellulose and hemicelluloses. Cellulose is a chemically monotonous composite material composed of hydrogen-bonded glucans. Hemicellulose is an obsolete terminology for a family of polysaccharides that hydrogen bond to cellulose microfibrils. The major types are xyloglucan (a glucan backbone decorated with branches of xylose, galactose, and fucose) and various types of xylans (branched D-1,4-linked xylose).

Feedstock polysaccharide composition is important to the overall biofuels production process in several ways. First, cellulose is highly recalcitrant to degradation because the structure does not provide readily accessible glycosidic linkages that can be hydrolyzed by cellulases. In theory, it may be possible to develop plants that have alterations in cellulose structure that facilitate hydrolysis. For instance, increasing the frequency of gaps in the glucans, altering the number of glucans per microfibril, introducing other sugars into the structure to decrease crystallinity, or intercalating small cellulose-binding peptides into the microfibrils to create deformations could substantially alter the recalcitrance. Additionally, there is evidence from genetic studies that cellulose and lignin provide similar types of structural integrity to cell walls. Thus, it may be possible to alter the ratio of lignin to cellulose by simultaneously decreasing lignin and increasing cellulose. To do this we need to know what regulates the amount of cellulose. We know that the cellulose synthase is highly phosphorylated and it seems likely that this modification regulates activity. Thus, we envision that this laboratory will have a program that includes mechanistic studies of cellulose synthase.

Relatively little is known about the synthesis of hemicelluloses. None of the genes that encode the enzymes that synthesize the backbones are known. Therefore, it has not been possible to really test the role of variation in hemicellulose content on the properties of cell walls, the corresponding plants, or the overall deconstruction process. We envision that one of the investigators in this laboratory will have a program focused on how hemicelluloses are synthesized, what factors control the amount of hemicellulose, and what roles hemicellulose plays in cell wall structure and function. An important early goal will be to identify enzymes that acetylate certain residues in hemicelluloses. The acetyl groups are released during deconstruction and inhibit the growth of micro-organisms. It may be possible to genetically decrease the amount of acetyl groups in the feedstocks without significant negative effects. A related goal will be to identify the enzymes that link lignin to hemicellulose. Altering or eliminating those linkages may allow much easier removal of lignin during preprocessing.

LIGNIN LABORATORY

Lead Investigator (I): *Chris Somerville (LBNL) – interim, New Recruitment (UCB/LBNL)*

Collaborators: *Manfred Auer (LBNL), Carlos Bustamante (UCB/LBNL), Rick Dixon (Noble Foundation), John Gertl (UIUC), John Ralph (Wisconsin)*

The design of a process for conversion of biomass to sugars depends very much on the composition of the biomass. Thus, there is a feedback loop between genetic modifications of biomass composition and the hydrolysis process. Although research in these two areas must proceed in parallel, the programs in EBI will be coordinated.

Lignin comprised about a quarter of the dry mass of the types of biomass that are likely to be used for biofuels production. Lignin occludes the polysaccharides, thereby retarding hydrolysis of the polysaccharides. Existing processes for pretreatment of biomass are designed to separate the lignin from the polysaccharides. By altering the structure of lignin, and its linkage to other cell wall components, much less costly and more benign pretreatments would be possible.

Lignin provides compressive resistance to plant cells and cannot simply be genetically eliminated without incurring deleterious consequences on plant productivity. However, a major objective of the program in this area will be the development of new types of lignin that are not known to occur in nature. We believe that there is a large opportunity to fundamentally change the overall deconstruction process by producing transgenic plants that accumulate a type of lignin with easily cleavable linkages (e.g., amide or ester) that would facilitate removal of lignin with processes that are much more benign than current processes. Furthermore, we envision that the lignin fragments produced in this way could represent a valuable feedstock for production of certain types of engineering plastics of the types used in the automobile industry. The research in this general area will require collaboration with individuals who have expertise in phenolic metabolism in plants and microorganisms (where novel pathways may be found) and also with individuals who specialize in the biological transporters that secrete different types of molecules (e.g., ABC transporters).

The scientists in the Lignin Laboratory will collaborate with colleagues involved in biomass conversion technologies to explore how changes in composition affect the overall deconstruction process. An important aspect of the EBI program in this area will be the development of imaging methods that allow visualization of lignin at the nanoscale. This is important as a means of understanding the molecular-scale processes that are involved in synthesis and deposition of lignin and also as a way of understanding how various pretreatments alter the conformation of lignin, or how various genetic changes alter lignin structure in transgenic plants. We envision that various types of imaging and chemical analysis will be required ranging from Raman nanoprobe studies at an LBNL beamline to atomic force studies at the Molecular Foundry, high-resolution EM studies at the LBNL National Center for Electron Microscopy, and NMR studies.

BIOTIC STRESS LABORATORY

Lead Investigator (I): Brian Staskawicz (UCB) – interim, New Recruitment (UCB/LBNL)

Collaborators: May Berenbaum (UIUC), Steve Clough (UIUC), Evan DeLucia (UIUC), David Kris Lambert (UIUC), Shauna Somerville (Carnegie), Mary Wildermuth (UCB/LBNL), Arthur Zangerl (UIUC)

Most of the plant species that are envisioned as dedicated energy crops are perennial grasses or trees. Because these species will be rotated relatively slowly, there is a danger that pests and pathogens may build up over time and limit productivity. It will be essential to have a clear understanding of the threats and to identify chemical and genetic methods to provide resistance to these threats. Thus, research in this area will involve placing test plots of many genotypes of relevant species of energy crops at many locations in order to identify the threats and to survey for the existence of genetic variability to such threats. Once the pests and pathogens are identified, it will then be necessary to identify efficacious commercial agrichemicals and to register them for use on the energy crops. The Biotic Stress Laboratory will also collaborate with breeders in industry or within the EBI to incorporate durable genetic resistance into pre-commercial or commercial cultivars of the energy crops.

ENVIRONMENTAL IMPACT AND SUSTAINABILITY ASSESSMENT LABORATORY

Lead Investigator (I): May Berenbaum (UIUC)

Collaborators: Ron Amundson (UCB/LBNL), Mark David (UIUC), Adam Davies (UIUC), Mary Firestone (UCB/LBNL), Ross Fitzhugh (UIUC), Susan Hubbard (LBNL), Angela Kent (UIUC), Rod Mackie (UIUC), Margaret Torn (UCB/LBNL), Tracy Twine (UIUC), Michelle Wander (UIUC)

Large-scale conversion of land from current use, i.e. from row crops, pasture, or conservation reserve program (CRP) to feedstock cropping to support biofuel processing plants, will require environmental assessments prior to planning approval. At a less formal level the UIUC surveys of landowners, farmers, and rural communities show that developing information on impacts is critical for gaining the support of the people who will live with this land use change. Key issues are how change will affect water use and quality, soil quality, soil erosion, biodiversity, landscape appearance, net greenhouse gas emissions, (GHG), particulate emissions, and the potential invasiveness of new biomass crops. The laboratory will quantify these effects to inform planning procedures, affected communities, Extension Services, and the public at large. Equally important is the sustainability of bioenergy feedstock cropping, particularly with respect to impacts on soil quality. These questions will be examined at multiple locations, but with the most intensive studies being conducted on the trials established by the Feedstock Production Laboratory.

Removal of substantial proportions of crop residues, such as corn stover, that are currently returned to the soil can lead to decreased soil organic matter (SOM), and in the longer-term decreased grain yield. This will also be detrimental to soil quality, affect nutrient loss to field drains and water quality, impact functional biodiversity of soil organisms, and result in a net loss of carbon to the atmosphere. In collaboration with the experiments outlined by the Feedstock Production Laboratory, we will examine these impacts at different levels of stover removal to establish a sustainable level of removal.

Perennial bioenergy crops are relatively new and far less is known of their impacts. Trials so far suggest that they will substantially increase SOM when they replace annual row crops. However, it is unclear how they affect soil microbial and detritivore diversity, and what long-term impacts these may produce. Equally it is unclear whether management can increase free-living nitrogen fixers in the perennial grass crops; this is of particular interest in *Miscanthus*, which is very closely related to sugarcane (99% DNA homology in genes so far sequenced). Sugarcane obtains significant quantities of nitrogen from free-living N-fixing associations.

Generally it is anticipated that these perennial crops will improve environmental quality, relative to other agricultural uses of the land. Low fertilizer requirements, extensive perennial root systems and winter harvest may improve water quality, decrease soil erosion, increase soil organic matter, and provide better habitat for nesting birds and insects, and cover for other animals. But these changes might also provide habitat for unwanted organisms. Other uncertainties will be the effect of adding the biofuel fermentation sludge residue back to the cropping system. These changes need to be documented in statistically valid comparisons to inform both impact assessments and appropriate management to minimize any detrimental changes.

Increased SOM deposition will result in increased sequestration at least in the short term. Establishing the turnover time of this carbon will be necessary to project longer-term sequestration and management that will slow turnover. Increasing SOM and altered quality associated with a new crop will affect microbial and soil insect diversity, including potential pathogens and pests. These changes may also in turn affect emissions of other greenhouse gases, notably methane and nitrous oxide. Eddy-covariance will be used to establish the net effect of altered land-use on greenhouse warming potential, and carbon credits that may be earned with biofuel cropping. Risk of genes and plants spreading into native communities will also be assessed and be used as a basis for any management recommendations to minimize such risks.

Large replicated plots (each 1 acre) of switchgrass, *Miscanthus*, corn, and soybean have already been established and will be extended (see Open-Air Feedstock RD&D Center) together with smaller trials at 8 sites in different climate zones and on different soils over a 400-mile transect of the US. These would form a basis for beginning these studies, which would be expanded as the agronomic trials are developed at more locations across the nation and new germplasm is introduced into trials. Parallel studies will be conducted at the poplar plantations that will be established.

Numerical models are needed for guiding the landscape and regional impacts of land use change at the larger scale, and to project longer-term impacts. These will be integrated into the field monitoring and experimentation.

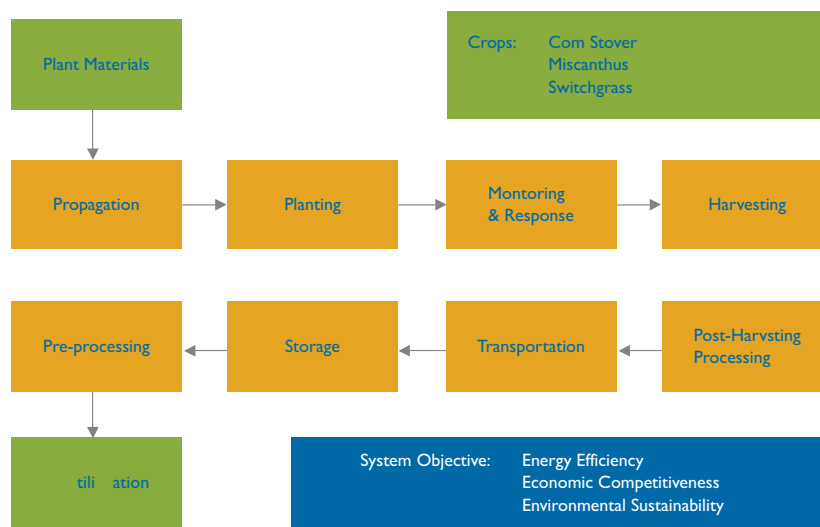
HARVESTING, TRANSPORT, AND STORAGE LABORATORY

Lead Investigator (I): KC Ting (UIUC)

Collaborators: Tony Grift (UIUC), Alan Hansen (UIUC), Max Shen (UCB), Lei Tian (UIUC), Qin Zhang (UIUC)

Efficient harvesting of cellulosic biomass from corn stover, *Miscanthus*, switchgrass, and wood species requires innovations in farm and pre-processing machinery. While companies are best placed to produce this equipment, we have provided the engineering base for over 100 major innovations currently used by companies for agricultural machinery in food production. We will now apply this experience to biofuel feedstock production and delivery. Cultural practice and materials handling operations of propagation, planting, monitoring and response, harvesting, post-harvest processing, transportation, storage, and pre-processing (preparation for use in the subsequent conversion processes) must all be examined.

Integration of Crop Science & Agricultural Engineering to advance energy crop production



Integration of Crop Science and Agricultural Engineering.

Four areas are seen as most important for achieving efficient production of energy crops. 1) Adapt precision agriculture technologies specifically for computerized planning, sensing, decision support/making, and managing of energy crop field production. This requires the establishment of an informatics platform for storing, analyzing (including modeling and simulation), and delivering biological and engineering information. 2) Test ways of improving existing machinery or developing new mechanical/electronic devices and equipment for handling of plants and plant materials in the propagation, planting, and harvesting phases of production. 3) Investigate necessary and effective material transformation and collection methods (e.g. baling vs. chopping, size reduction, densification, etc.), as well as materials handling, conditioning, transportation, and storage. Transport and storage issues will be an integral aspect of designing the harvesting equipment. 4) Overarching these and integrated with the objectives of the Feedstock Production Laboratory is to use systems engineering to refine system objectives, identifying constraints and finding alternative solutions.

This framework will guide the mission of improving the efficiency of the whole operation from propagation to delivery of material to plant. Our initial analyses have identified early specific targets for improvement. 1) To increase efficiency of operation, combine stover baling with grain harvesting. 2) Examine for all crops baling vs. chopping with densifying as a better means of preparation for transport and pre-processing. 3) Examine field storage methods including with and without waterproof wraps for a just-in-time delivery system. This will include tests with biodegradable film and applying bale-coating derived from waxes recycled from the bioconversion process. 4) Improve and develop machinery for lifting *Miscanthus* rhizomes, planting *Miscanthus* rhizomes, and sowing *Miscanthus* and switchgrass seed.

Biomass Depolymerization Program

The hydrolysis of lignocellulose into fermentable sugars is hampered by slow reaction rates arising from the crystalline cellulose content of the lignocellulosic feedstock and the inaccessibility of enzyme adsorption sites. This is the result of intricate links between the structure of the lignocellulosic material and the limited availability of enzymatic binding sites. The long D-1,4 linked D-anhydro-glucopyranoside units form a network of inter- and

intra-molecular parallel hydrogen bonds and that are stacked by van der Waals forces, forming a material that is highly recalcitrant to hydrolysis.

Present methods for deconstructing lignocellulose are costly and energy intensive. A central aim of this component of the EBI will be to understand the physical and chemical fundamentals of lignocellulose deconstruction and enzymatic conversion into C₅ and C₆ sugars and lignin byproducts. A long-term goal will be to develop one or more microbes expressing cellulases or cellulosomes that can be used in a consolidated bioprocess with organisms that utilize the simple sugars and lignin products to make a range of biofuels, such as ethanol, butanol, or hydrocarbons.

FEEDSTOCK PRETREATMENT LABORATORY

Lead Investigator (I): *Harvey Blanch (UCB/LBNL)*

Collaborators: *Uli Dahmen (LBNL), Bruce Dale (Michigan State), Stephen Leone (UCB/LBNL), Richard Saykally (UCB/LBNL), Evan Williams (UCB/LBNL)*

Pretreatment is typically accomplished with established technologies derived from the pulp and paper industry such as dilute acids (HCl, H₂SO₄), explosive decompression (steam), hot water, or treatments with organic solvents. Acid hydrolysis leads to degradation products that are often inhibitory and significantly lower the glucose yields. Glucose and xylose degradation products that result from the pretreatment methods include hydroxymethylfurfural (HMF) and furfural, which produce levulinic and formic acids that inhibit the subsequent fermentation of sugars to ethanol. In contrast, cellulase hydrolysis results in almost no by-product formation. Pretreatment processes that increase the surface area accessible to water (largely excluded due to the packing of cellulose fibrils) and provide enzyme binding sites will thus substantially increase glucose yields.

These problems underline the importance of developing a pretreatment process that a) converts the initial lignocellulosic material into an easily hydrolysable format and b) must not produce any inhibitory components that will negatively impact the downstream processing of that biomass into ethanol or other biofuels. Promising new approaches include ionic liquid solvents, liquid hot water, and ammonia fiber explosion. Each approach results in varying degrees of cellulose de-crystallization, lignin melting and rearrangement, and hemicellulose solubilization and hydrolysis. Quantifying and imaging pretreatment processes is thus a first step to developing predictive models to optimize the pretreatment processes for subsequent enzymatic depolymerization of lignocellulosics. Lignocellulose will be imaged at nanometer resolution using the LBNL synchrotron and EM facilities. Drying of samples (required for techniques such as EM, mercury porosimetry) may collapse pore structures, and techniques to characterize wet fibers are required (e.g., solute exclusion, NMR, cryo-TEM). We will use our expertise in high-pressure cryo-TEM, and atomic force microscopy to develop a fundamental understanding of the relevant structures via direct imaging. This will provide direct insight into the degree and sites of attack arising from various pretreatment processes.

The effects of the following pretreatments will be characterized at the molecular level in the Feedstock Pretreatment Laboratory with a view to using mechanistic insights to improve the processes. We will also examine the effects of genetic changes in biomass composition on the outcomes of these pretreatments.

- **Ionic liquids (ILs).** Several ionic liquids show substantial ability to solubilize cellulose (e.g., 3-methyl-*N*-butylpyridinium chloride [C₄ampy]Cl and 1-*N*-butyl-3-methylimidazolium chloride [C₄mim]Cl have solubilities of 39% and 25%). Regenerated cellulose, lacking crystalline regions, can be precipitated with antisolvents such as water or alcohols. Water displaces the IL from cellulose, permitting recovery of the IL once the precipitated cellulose is removed. A range of ILs will be examined for their ability to dissolve lignocellulosics and disrupt crystalline regions.
- **Organosolv processes.** Lignocellulosics can be fractionated by hot aqueous ethanol, with sulfuric or Lewis acids as a catalyst. The pulp and liquor are separated; the lignin is substantially solubilized in the aqueous ethanol phase; the pulp contains residual lignin and most of the carbohydrate present in the lignocellulosic biomass. Lignin is recovered from the aqueous ethanol solvent by dilution with water. Subsequent washing of the pulp yields a material suitable for enzymatic hydrolysis with high glucose yields (90%).
- **Liquid hot water pretreatment (hydrothermolysis).** Solvolysis by hot liquid water at 200-230°C for 15 min at 350-400 psig. All hemicellulose is converted to monomer, with 4-22% of the cellulose and 35-60% of the lignin removed. The remaining solids have improved digestability. Size reduction of biomass is not required as hot water pretreatment causes lignocellulosics to break apart. Softwoods are less susceptible. The effects of this pretreatment on lignin need to be understood. Maintaining pH control (above 4-5) may be beneficial. The chemistry of this process and physical mechanisms require understanding for optimization and application to modified feedstocks.
- **Ammonia fiber explosion (AFEX).** This process yields very high rates of enzymatic hydrolysis with low enzyme loadings. This process is suitable for agricultural residues, is less well suited for hardwoods, but is not attractive for softwoods. A 5-15% ammonia solution at 160-180°C is passed through the biomass. Aqueous ammonia reacts and depolymerizes lignin, improving enzymatic hydrolysis. The cost of ammonia requires its recycle, however the lower temperature operations reduce sugar degradation.

ENZYME DISCOVERY LABORATORY

Lead Investigators (2): *Phil Hugenholtz (LBNL), and New Recruitment (UCB/LBNL)*

Collaborators: *Jamie Cate (UCB/LBNL), Douglas Clark (UCB/LBNL), Jonathan Eisen (UCD/LBNL), Roderick Mackie (UIUC), Michael Marletta (UCB/LBNL), Bryan White (UIUC)*

The Enzyme Discovery Laboratory will use high-throughput methods to discover new sources of useful hydrolytic enzymes by surveying and screening genomes from understudied habitats such as tropical soils, termite guts, and rumen where lignocellulose degradation is a dominant metabolic activity. While the majority of the industrial enzymes known to date have been derived from bacteria and fungi, archaea, the third domain of life, are of particular interest to us because most of the archaeal species identified to date have been identified from extreme environments. Characterization of genomes from these organisms offers an opportunity to harvest genes compatible with integration of process steps associated with cellulosic biomass deconstruction. This is especially true in the case of integration of pretreatment and hydrolysis. Several notable hydrolases have been identified in

archaea that are promising candidates to optimize bioconversion of recalcitrant cellulose to fermentable sugars by running the process of saccharification at lower pH and higher temperatures and serve as model systems for the bioinformatics analysis of the process. The industrial process benefits of using enzymes from extremophiles (extremozymes) include reduced risk of contamination, improved mass transfer rates, lower viscosity, and higher solubility of substrates.

Organisms that grow near ambient temperature, or near to the optimal growth temperature of organisms used for downstream conversion, will also be surveyed for new enzymes that degrade lignocellulose or alleviate inhibition of various steps under development in the Integrated Bioprocessing Laboratory. A key to the screening process will be new high-throughput assays that mimic realistic industrial reaction conditions. The choice of operating temperature is crucial for obtaining the most energy-efficient process of biomass deconstruction. An example where temperature optimization paid big dividends was the development of enzyme additives for laundry detergents. These enzymes, which are robust yet function in lukewarm water, are now ubiquitous in the laundry detergent business, and have contributed to significant energy savings. At present, no mesophilic organism that produces cellulosomes has had its genome sequenced. The EBI will help to fill this gap in our understanding by sequencing genomes (through our unique connection to JGI) of organisms that produce potentially useful cellulosomes, in order to accelerate mechanistic studies carried out by the Enzyme Structure and Function Laboratory.

ENZYME STRUCTURE AND FUNCTION LABORATORY

Lead Investigator (I): *Jamie Cate (UCB/LBNL)*

Collaborators: *Douglas Clark (UCB/LBNL), Uli Dahmen (LBNL), John Gerlt (UIUC), Stephen Leone (UCB/LBNL), Michael Marletta (UCB/LBNL), Evan Williams (UCB/LBNL), Haw Yang (UCB/LBNL)*

Improving cellulase activity is predicated on enzyme assays that are readily used to analyze biomass depolymerization. The challenge in studying lignocellulose depolymerization is that the substrate is insoluble and heterogeneous. We will employ multiple strategies to probe depolymerization on different time and length scales. Assays based on soluble substrates are useful in determining initial kinetics, product inhibition, and the energetics of substrate binding. However, correlating activity on defined substrates with activity against pretreated biomass presents significant challenges, and the pretreated material must be characterized at a microscopic level. Prior assays will need to be standardized and optimized for comparison to the anticipated feedstock characteristics. We will design new substrates and products for cellulosomes and free enzymes that will be useful for enzymology and for x-ray crystallographic experiments. Fluorogenic substrates will be synthesized that generate UV chromophores upon hydrolysis. The fluorogenic substrates will increase the sensitivity of established assays, and will be used to carefully probe enzyme activities.

Cellulases and cellulosomes attack the surface of insoluble lignocellulose, and can also be inhibited by adsorption to these surfaces. We will, therefore, use several approaches for imaging of wet samples of lignocellulose during depolymerization, including x-ray diffraction and spectroscopy, electron microscopy, and nonlinear optical molecular imaging, in order to determine the sites of attack by the various enzymes identified in the Enzyme Discovery Laboratory, and sites that lead to inhibition. We also plan to synthesize and purify nanometer-sized cellulose crystals that are well defined in their chemical composition and structure. These cellulose crystals will be designed to mimic the adsorption properties that are thought to inhibit cellulases. The resulting nano-crystals will be tested for their effects on enzyme activity and used in co-crystallization experiments. Given their small size, these cellulose crystals should be amenable to co-crystallization with cellulases or cellulosome components, as protein packing in protein crystals often leaves large solvent channels.

The complex interactions between lignocellulose and cellulosomes due to their high degree of heterogeneity will require more than bulk measurements to decipher. We will use newly developed microscopes for single-molecule spectroscopy to probe the dynamics of cellulosome assembly and function. We will track the assembly and export of these complexes *in vivo*. Furthermore, in an effort to improve depolymerization efficiency, we will study the nature of lignocellulose degradation to determine the degree of cellulosome and cellulase processivity and cooperativity. These studies should provide fresh insights into ways of pretreating cellulosing materials and may afford methods for directed modification of key enzymes.

ENZYME EVOLUTION AND ENGINEERING LABORATORY

Lead Investigator (I): Michael Marletta (UCB/LBNL) – interim, New Recruitment (UCB/LBNL)

Collaborators: Jamie Cate (UCB/LBNL), Gavin Crooks (LBNL), Philip Geissler (UCB/LBNL), Phil Hugenholtz (JGI), Kimmen Sjolander (UCB/LBNL), Humin Zhao (UIUC), Ron Zuckermann (LBNL)

We will employ two parallel methodologies to improve enzyme performance in industrial-scale lignocellulose depolymerization, namely enzyme evolution and computational design. The goal of the Laboratory will be to use the following experimental and computational approaches to produce optimal enzymes that could be included in, for example, hybrid cellulosomes that could efficiently tackle the real-world substrates that will be used on an industrial scale.

Our experimental approach will use mutagenesis in combination with DNA shuffling of metagenomic libraries that include genes identified in the Enzyme Discovery Laboratory. Successful examples of the use of industrial enzymes discovered by metagenomic enzyme libraries include nitrilases developed by Diversa and alcohol dehydrogenases developed by Schering Plough. As such, metagenomics represents a powerful tool to access the biodiversity of native environmental samples like compost communities and extremophile communities that are teeming with organisms with industrially interesting enzymes.

We will perform computational modeling and simulations to guide the site-directed mutagenesis coupled to enzyme screening and isolation of desired traits, such as reducing product inhibition and byproduct inhibition. These efforts will be aided by the mechanistic enzymology carried out in the Enzyme Structure and Function Laboratory. The strength of computational approaches is that all point mutations can be systematically sampled both individually and in combination with each other to engineer protein properties. Mutations identified computationally will be experimentally introduced at those specific sites and the resultant mutants will be screened for the desired increased functionality.

INTEGRATED BIOPROCESSING LABORATORY

(shared with the Biofuels Production Program)

Lead Investigator (I): Chris Voigt (UCSF/LBNL)

Collaborators: Adam Arkin (UCB/LBNL), Harvey Blanch (UCB/LBNL), Hans Blaschek (UIUC), Douglas Clark (UCB/LBNL), Jay Keasling (UCB/LBNL), Roderick Mackie (UIUC)

A long-term goal of lignocellulosic bioconversion is to develop integrated single-vessel systems in which raw materials are simultaneous depolymerized and fermented to products. In addition to reducing costs associated with multiple processing steps, simultaneous saccharification and fermentation of cellulosic materials reduces intermediate product concentrations and reduces inhibitory effects (i.e., cellobiose hydrolysis by β -glucosidase is inhibited by glucose). Ideally, the major enzymes would be produced by the fermenting organisms. Accomplishing

this by modification of existing industrial organisms will require not only addition of genes for hydrolytic enzymes but also substantial increases in the amount of protein secreted. By adding supplemental enzymes from various sources (plant, fungal), the accessibility of various enzymes to their substrates may be enhanced and productivity increased. In consolidated bioprocessing, all hexose and pentose sugars must be fermented. Thus, approaches to simultaneous operation of many metabolic pathways must be developed. For instance, modifications that overcome the inhibition of pentose conversion to ethanol by glucose are required. Identification of enzymes and microorganisms to develop integrated approaches will rely on the capabilities of the Enzyme Evolution and Engineering Laboratory, and the Enzyme Structure and Function Laboratory.

Fermentative yeasts are typically unable to convert xylose to ethanol, or use pentoses as carbon sources for growth. Although efforts to clone xylose isomerase (a direct pathway) into yeast proved unsuccessful for ethanol production, cloning the alternative metabolic pathway -xylose reductase (xylose to xylitol), xylitol dehydrogenase (xylitol to D-xylulose), and xylulokinase (D-xylulose to D-xylulose-5-phosphate) permits *Saccharomyces* to ferment xylose together with glucose. However, a number of barriers remain. The co-fermentation process is slow and ethanol yields are not high due to by-product formation. The problem of cofactor preferences (NAD/NADP) among the enzymes remains unresolved, and glucose transport across the yeast membrane is preferred over xylose. Arabinose is a major component of some biomass, such as corn fiber, and although the *E. coli* arabinose-converting genes have been cloned into *Saccharomyces*, poor ethanol yields result and substantial improvements are required. Thus, significant opportunities for re-engineering yeast pathways to provide maximal carbon flow to ethanol (or any other fuel) exist. Achieving these goals will draw on the Pathway Engineering Laboratory's ability to rapidly clone and express new pathways in microorganisms, and to provide *in situ* assays of intracellular enzyme activities.

Pretreatment processes, particularly thermochemical, produce substances that inhibit growth and ethanol formation in fermentation. Furfural, for example, is a known inhibitor, as are soluble phenolic compounds derived from lignin depolymerization. Understanding the nature and mechanisms of inhibition may provide opportunities to develop inhibitor-resistant yeast or bacteria and enhance ethanol yields. This will require production of enzymes involved in the inhibited pathways, characterizing their structure and developing resistant variants.

Because of its strong ties to biomass depolymerization and fuel production, this laboratory is grouped under both programs.

BIOFUELS CHEMISTRY LABORATORY
(shared with the Biofuels Production Program)

Lead Investigator (I): Alex Bell (UCB/LBNL) – interim, New Recruitment (UCB/LBNL)

Collaborators: Harvey Blanch (UCB/LBNL), Enrique Iglesia (UCB/LBNL), Alex Katz (UCB)

The Biofuels Chemistry Laboratory will explore the development of new chemical catalysts for conversion of biomass to fuels. A priority objective will be to explore the development of new catalysts for the cleavage of glycosidic linkages. The development of such catalysts could obviate concerns about hydrolysis of cellulose under mild conditions and could greatly reduce the formation of toxic byproducts by current pretreatment processes.

The catalytic conversion of glucose to *n*-alkanes provides an alternative route to liquid fuels. We propose to define the compositional and structural requirements of catalysts that can be used for the various stages of glucose conversion to liquid alkanes. It is envisioned that these catalysts will take the form of solid acids and bases, and supported metals. Solid acid catalysts are needed for the dehydration of glucose to HMF, whereas solid base catalysts are needed to promote aldol condensation of HMF with acetone and other ketones. Supported metal

catalysts are needed to hydrogenate carbonyl groups and olefinic groups, whereas acid catalysts are required for the dehydration of polyalcohol intermediates. As acid catalysts we will investigate metal oxides, such as dispersed tungstena and heteropolyacids, dispersed onto zirconia, a support that is well suited for use under aqueous conditions. We will also examine the synthesis of mesoporous block copolymers, which can be prepared with monomers containing sulfonic acid and other acid on side chains. Dispersed metals, such as Pt, will be placed on zirconia since this material is more stable in aqueous solutions than conventional supports, such as alumina or silica, particularly at modest pHs above and below 7.

A further objective will be to see whether all three functionalities — dehydration, aldol condensation, and hydrogenation — can be combined into a single catalyst. This approach can be envisioned using mesoporous, poly-block copolymers. Experiments will be performed both with glucose as the starting material and with model compounds identified as reaction intermediates. Use of the latter materials will facilitate the definition of site requirements for specific classes of reactions. Measurements of kinetics will be coupled with investigations of reaction mechanism. An important objective of this work will be the identification of what is required in the way of catalyst composition and structure to obtain high activity and selectivity for particular classes of reactions. The proposed experimental work will be complemented by theoretical calculations to establish catalyst structure-function relationships.

Because of its strong ties to biomass depolymerization and fuel production, this laboratory is grouped under both programs.

Biofuels Production Program

The production of biofuels is hampered by toxicity of lignocellulose depolymerization products and the fuels to the microbial producer, the inability of the microbial host to withstand processing conditions, inefficient conversion of the products of lignocellulose depolymerization into fuels, and a lack of biosynthetic pathways for production of potential fuels and fuel additives. The Biofuels Production Program of EBI will focus on alleviating these limitations, not only as it relates to ethanol production, but also higher alcohols (e.g., butanol), alkanes, and esters. First, we will characterize the toxicity of various fuels and biomass monomers to potential microbial hosts using the latest experimental technologies in functional genomics and computational models. This information will be used to engineer several platform hosts to be tolerant of the various processing conditions likely to be found in producing biofuels from lignocellulosic biomass. Not only will we develop organisms that are capable of utilizing all of the sugars released from lignocellulosic biomass, we will also develop organisms capable of producing fuels from the aromatic monomers found in lignin, from sunlight through photosynthesis, and from synthesis gas generated during the pyrolysis of biomass. Making use of our strength in synthetic biology and metabolic pathway design, we will develop novel biosynthetic pathways that will allow us to synthesize any number of potential fuel molecules from central metabolic intermediates that exist in all microbial cells. These pathways will be modular so that they can be introduced into any microbial host for production of the desired fuels or fuel additives. Finally, we will use our strengths in microbial pathway optimization and process optimization to create industrial-strength microorganisms capable of efficiently converting biomass to fuels under industrial conditions.

SYSTEMS BIOLOGY LABORATORY

Lead Investigator (I): Adam Arkin (UCB/LBNL)

Collaborators: Hans Blaschek (UIUC), Robert Dibble (UCB/LBNL), Jonathan Eisen (UCD/LBNL), Michael Eisen (UCB/LBNL), Aindrila Mukhopadhyay (LBNL), Nathan Price (UIUC)

A major barrier in the efficient use of biomass-derived sugars is that microbes have a complex network of poorly understood regulatory networks that are designed to achieve different metabolic outcomes from those we desire. Problems include inhibition by deleterious products formed during biomass hydrolysis, yields limited by accumulation of alternative products, unnecessary microbial growth, suboptimal specific productivity resulting from various limitations in the biosynthetic pathways for products (i.e., fuels) and mismatches in conditions with the hydrolysis enzymes, and inhibition by the main fermentation product (e.g., ethanol or higher alcohols) with concomitant low alcohol titer. These and related problems contribute to the cost of lignocellulosic ethanol by increasing capital expenditure, reducing product yields, and increasing water volumes that must be handled as part of relatively dilute product streams.

The new tools of systems biology, synthetic biology and evolutionary approaches will facilitate the development of predictable models that can be used to direct metabolic engineering and synthetic biology approaches to development of improved biotransformation processes. The key to systems biology is the development and use of computational models that incorporate whole system types of data (e.g., whole genome transcriptome, proteome, or metabolome datasets) into predictive models. Such models need to be developed to address questions such as what mechanisms control glycolytic flux, and what are their implications for cellular metabolism? What molecular mechanisms are used by cells to cope with such environmental challenges as high concentrations of sugars and ethanol and the presence of inhibitors from biomass hydrolysis? What genetic and physiological characteristics mediate evolution of wild-type organisms into robust laboratory or industrial strains, and which ones control their functional state in the process environment?

PATHWAY ENGINEERING LABORATORY

Lead Investigator (I): Jay Keasling (UCB/LBNL)

Collaborators: Adam Arkin (UCB/LBNL), Phil Hugenholz (JGI), Susan Marqusee (UCB/LBNL), Hiroshi Nikaido (UCB/LBNL), Jasper Rine (UCB), Jeremy Thorner (UCB), Huimin Zhao (UIUC)

No microorganism currently has all of the capabilities that are desirable for production of biofuels from cellulosic biomass. For instance, current industrial strains of yeast are only capable of producing ethanol from glucose, so recombinant ethanologenic organisms (e.g., yeast, *E. coli*, and *Z. mobilis*) have been created to ferment both glucose and xylose by the addition of genes for entire pathways. This laboratory will focus on the identification and characterization of biofuels-relevant pathways from a wide variety of organisms. This laboratory will engage in collecting and testing strains for useful capabilities and the identification of the enzymes and corresponding genes for relevant pathways at a sufficient level of resolution to permit transfer of pathways to new hosts. The laboratory will identify pathways for fermentation of all major sugars and also identify pathways for synthesis of various potential fuels ranging from alkanes and medium-chain alcohols to terpenoids, xylenes, and other hydrophobic molecules.

As mentioned above, most methods of biomass pretreatment to produce hydrolysates also produce side products that are inhibitory to growth of microorganisms and final product titers. The basis for these inhibitory effects needs to be understood and strains developed through rational pathway engineering that exhibit resistance

to these inhibitors—preferably by allowing the improved strains to catabolize the inhibitors—thereby improving overall process efficiency.

In addition to the work in constructing pathways for catabolizing biomass monomers and synthesizing potential fuel molecules, the Pathway Engineering Laboratory will collaborate with the Fossil Fuel Bioprocessing Laboratory to characterize metabolic pathways that may be useful for this application. These will include pathways for desulfurization of coal and oil.

HOST ENGINEERING LABORATORY

Lead Investigators (3): *Hans Blaschek (UIUC), Tasios Melis (UCB/LBNL), Krishna Niyogi (UCB/LBNL)*

Collaborators: *Harvey Blanch (UCB/LBNL), Douglas Clark (UCB/LBNL), John Coates (UCB/LBNL), Jay Keasling (UCB/LBNL), Dan Koshland (UCB), Thanos Lykidis (LBNL), Chris Voigt (UCSF/LBNL)*

The goal of this laboratory is to engineer a variety of hosts to be used as platforms for the synthesis of fuels. This work will include optimization of energy source utilization, engineering tolerance to biomass hydrolysis products and fuels, elimination of unwanted side reactions in native host metabolism, and the development of gene expression tools for these hosts. The platform hosts will be chosen around three possible energy sources: sugars released from cellulose-hemicellulose hydrolysis, photosynthesis, and syngas ($\text{CO} + \text{H}_2$) generated by biomass pyrolysis. To enable the rapid development of host microorganisms, this laboratory will utilize tools and approaches from several interconnected fields including metabolic engineering, directed evolution, bioinformatics, systems biology, and synthetic biology in order to engineer these microorganisms to overproduce biofuels. (These approaches have been successfully used to engineer microorganisms for the production of various products such as amino acids, lactic acid, and 1,3-propanediol on an industrial scale.) Incorporation of the pathways constructed in the Pathway Engineering Laboratory into these platform hosts would allow one to produce any number of fuels from each of these energy sources.

Informed by the genome sequences of these platform hosts and the work in the Systems Biology and Pathway Engineering Laboratories, the researchers in this laboratory will work to engineer microbial hosts to tolerate high concentrations of fuels and biomass hydrolysis products (for the platform hosts that utilize these carbon sources to produce fuels). This work will include manipulating membrane and cell wall structures, engineering transporters, and constructing pathways to catabolize toxic hydrolysis products.

The efficiency of energy source conversion will be a key aspect of the work in this laboratory. Besides the elimination of side reactions that reduce efficiencies, key junction reactions will need to be engineered to enhance metabolic flux for biofuels production and remove pathway bottlenecks. For photosynthetic platform hosts, improvements in the solar conversion efficiency will be implemented to accelerate growth and improve biomass/biofuel yields.

Finally, in conjunction with the Synthetic Biology Research and Development Center, we will develop gene expression tools and methods that will allow us to rapidly and predictably engineer the platform hosts. These tools will include vectors, promoters and ribosome binding sites of various strengths, mRNA stability elements, and the like. In particular, many existing hosts (e.g., Clostridia such *C. beijerinckii* and *C. acetobutylicum*) are already good producers of some fuels but have few tools for engineering their metabolism or tolerance to fuels and biomass hydrolysis products.

The developed microbes will be tested for use at the industrial pilot scale in the integrated bioprocessing research laboratory (IBRL) at UIUC (see facilities list).

Fossil Fuel Bioprocessing and Carbon Sequestration Program

In addition to the biofuels program, the EBI will have three laboratories that will explore novel opportunities to use biological processes to alter oil recovery, fossil fuel processing, and biological carbon sequestration. These laboratories will employ many of the same kinds of approaches used in the biofuels-oriented laboratories and are expected to be well-integrated into the intellectual and scientific culture of the EBI.

FOSSIL FUEL BIOPROCESSING LABORATORY

Lead Investigator (I): *John Coates (UCB/LBNL)*

Collaborators: *Gary Andersen (LBNL), Jill Banfield (UCB/LBNL), Robert Dibble (UCB/LBNL), Terry Hazen (LBNL), Paul Ludden (UCB/LBNL)*

A systematic effort to enrich and isolate naturally-occurring organisms capable of “Cracking” oil or coal involves testing soil and water samples from areas that have been long been contaminated with oil and coal particles. An example of successful employment of this approach is the isolation of a thermophilic, CO utilizing organism from charcoal beds. We will test many samples of oil-contaminated soil, near refineries, from oil tanker walls, shale oil samples, coal beds, tar sands, etc. Samples will be presented with various substrates (coal powder, oil, shale oil, tar) under a variety of growth conditions. Information from industry scientists may also be helpful in identifying sites with useful diversity. For instance is there a site with unexplained curdling of oil samples? Have microbial mats ever been observed at the edge of a contaminated oil site? Are there samples where organisms (molds, bacteria, lichens) have been observed to grow on coal samples?

In addition to screening for useful microbial capabilities, we will develop assays for breakdown of oil, coal or shale oil. It is likely that subtle assays will be necessary to identify the initial positive isolates. For example, if samples of coal with a known ^{13}C distribution were mobilized or solubilized by microbes, this could be detected by isotope ratio mass spectroscopy of very small samples. Once positive samples are identified, they will be moved quickly into the pipeline of other components of the project, including the sequencing of genomes for the newly discovered organisms at JGI, isolation of the enzymes involved, and incorporation of genes for those enzymes into the “enzyme evolution” project to enhance stability and catalytic capabilities of those new catalysts.

Because of the recent discovery of organisms that convert CO_2 and H_2 to alkanes, we will also explore the possibility of using coal syngas as a feedstock for microbial fuel production.

MICROBIAL ENHANCED OIL RECOVERY (MEOR) LABORATORY

Lead Investigator (I): *Terry Hazen (LBNL)*

Collaborators: *Gary Andersen (LBNL), John Coates (UCB/LBNL), Mark Conrad (LBNL), Stefan Finsterle (LBNL), Susan Hubbard (LBNL), Ernest Majer (LBNL)*

MEOR techniques involve the introduction of microorganisms, nutrients, and oxygen into the reservoir to produce metabolic events that lead, by a variety of mechanisms, to enhanced oil recovery. Several challenges prohibit the routine, cost-effective, and large-scale implementation of MEOR. To overcome these challenges, it is imperative to 1) develop an understanding of native reservoir bacteria and their potential to enhance oil recovery, through

alteration of crude oil molecular structure or associated flowpaths; 2) engineer microbial strains to promote traits that facilitate recovery; 3) predict microbial growth and reactivity within petroleum reservoirs with enough accuracy to guide MEOR treatments; 4) develop *in situ* procedures to implement MEOR effectively and over large spatial scales; and 5) monitor treatments and associated products in real-time and over field-relevant scales.

The MEOR Laboratory will tackle all five research challenge areas by leveraging Berkeley-developed advances that have been extensively used to remediate environmental contaminants, remotely image biogeochemical transformations in subsurface systems, and predict coupled biogeochemical-hydrological processes associated with such transformations. For example, Berkeley scientists have extensive experience in the development of *in situ* and *ex situ* bioremediation strategies for environmental contaminants (including hydrocarbons) that are based in part upon Berkeley-developed technologies, such as the groundbreaking Phylochip technology (which is able to simultaneously classify all members of a microbial community, and measure their physiological activity, without prior knowledge of microbial composition), and the “bioreactor” technology. Moreover, the effectiveness of *in situ* MEOR strategies will strongly depend on the spatial distribution of microbes and nutrients within the reservoir and associated biogeochemical reactions. The Berkeley-developed TOUGH2 family of multiphase flow and reactive transport codes will provide a foundation for simulating the MEOR processes needed to guide MEOR design and to predict treatment longevity. Finally, MEOR transformations *in situ* will be monitored using C, N, and O isotopes to quantify bioremediation rates, time-lapse geophysical methods to track pore fluid replacement, changes in mineralogy, and the generation of gases or biofilms that are expected to accompany MEOR processes.

BIOLOGICAL CARBON SEQUESTRATION LABORATORY

Lead Investigator (I): *Margaret Torn (UCB/LBNL)*

Collaborators: *Gary Andersen (LBNL), Jill Banfield (UCB/LBNL), Sally Benson (LBNL), Mark Conrad (LBNL), Mary Firestone (UCB/LBNL), Terry Hazen (LBNL), Hoi-Ying Holman (LBNL), Susan Hubbard (LBNL), Ernest Majer (LBNL), Larry Myer (LBNL), Curt Oldenburg (LBNL)*

The goal of the Biological Carbon Sequestration Laboratory is to render biofuels production, deconstruction, and fermentation processes carbon neutral (or preferably, carbon negative) through terrestrial carbon sequestration. Terrestrial sequestration involves the removal of CO₂ from the atmosphere by photosynthesis and the storage of CO₂ in biomass, soils, and sediments. To enhance such sequestration, the options are to increase the net fixation of CO₂ by photosynthetic organisms, to enhance the accumulation of soil organic matter, to reduce the emission of CO₂ from soils, and to increase the capacity of degraded lands to sequester carbon. There is a significant opportunity to enhance these terrestrial CO₂ uptake and storage processes through molecular bioengineering.

Geologic sequestration involves the use of depleted oil and gas reservoirs, saline aquifers, and other natural formations to store injected CO₂. Microbial engineering also has the potential to tackle some of the key challenges in geological sequestration, such as those associated with storage optimization and integrity. For example, microbial engineering can be used to facilitate geochemical reactions that enhance CO₂ storage, by promoting microbial processes that facilitate mineral trapping of CO₂ or through the development of precipitates and biomass that can seal natural fractures, which could otherwise serve as conduits for CO₂ seepage. Additional challenges associated with both geological and terrestrial sequestration include the development of an improved understanding of plant-soil-microbe-mineral-pore fluid processes involved in sequestration; prediction, monitoring, and validation of sequestration processes; and life cycle and risk assessment.

By leveraging LBNL's and UC Berkeley's expertise in microbial ecology, transport simulation, and imaging

and their world-recognized carbon sequestration leadership, the Biological Carbon Sequestration Laboratory will develop efficient biological carbon sequestration approaches. Using theoretical, numerical, and experimental approaches, research will be performed within four thrust areas: biological exploration and manipulation to facilitate enhanced sequestration, *in situ* implementation of developed procedures under natural field conditions, process simulation and prediction, and sequestration monitoring and verification.

Discovery and Development Support Centers

The five Discovery and Development Support Centers will be service laboratories managed by experienced PhD-level scientists who are not EBI Investigators. Additionally, each center will be directed by an EBI Investigator most closely associated with the work in that center. These laboratories will provide specialty technical services to members of the EBI. Additionally, the scientists employed in these centers will undertake focused research on development of improved technical methods that will facilitate research by the research laboratories. Priorities for services and technical innovation will be established in consultation with the management committee. Because the largest group of EBI scientists will be located at the UCB site, these facilities will be located at UCB, excepting the Open-Air Feedstock RD&D Laboratory, which will be at UIUC as this is the focus of the feedstock crops development and production research.

CHEMISTRY CENTER

Center Director: *Michael Marletta (UCB/LBNL)*

Several of the research programs within EBI will need access to natural or synthetic chemicals that are not commercially available. In particular there will be a need for synthesis of sugar nucleotides, oligosaccharides, lignin derivatives, fluorescent-labeling reagents (e.g., modified FLAsH tags), affinity ligands, analogs of bioactive compounds, and many other chemicals that are not available commercially. The Chemistry Center will be staffed with synthetic and analytical chemists with experience in relevant areas of chemistry. The group will make informed decisions about whether to contract out a specific synthesis requirement or whether it can be done in-house. Because it is likely that chemical genetics will be employed as a research tool by several groups, the Chemistry Center may assist with development of analogs and with sample identification. The group will also provide analytical expertise in the structural identification of oligosaccharides, lignins, and other natural molecules based on analytical methods including IR, NMR, and mass spectrometry. In most cases, the group will utilize analytical instruments available at the parent institutions.

IMAGING CENTER

Center Director: *Paul Adams (LBNL)*

A number of research programs at EBI will require access to biological imaging of various types. Confocal imaging will be necessary for investigations involving live-cell imaging of proteins and for subcellular localization studies. High-resolution electron microscopy and atomic force imaging will be necessary for experimental work focused on feedstock processing and also for experiments leading to production of modified feedstocks. Cryo-electron microscopy and AFM may also be important for visualization of nanomachines, such as cellulosomes, involved in biomass processing and for visualizing protein complexes involved in polysaccharide synthesis. Variants of electron tomography will be important in understanding the nanoscale organization of lignin and polysaccharides in intact cell walls from various sources.

Scientists employed in the Imaging Center will assist investigators from the various other groups to access state-of-the-art imaging technologies and will also develop new imaging technologies that create new experimental opportunities. Because of the high demand on campus for certain types of imaging instruments, we envision that the Imaging Center will maintain some types of instruments (e.g., confocal microscopes). In other cases it may be preferable to use instruments such as electron microscopes that are available at centralized facilities on both the UCB and UIUC campuses.

COMPUTATION AND DATA MANAGEMENT CENTER

Center Director: *Adam Arkin (UCB/LBNL)*

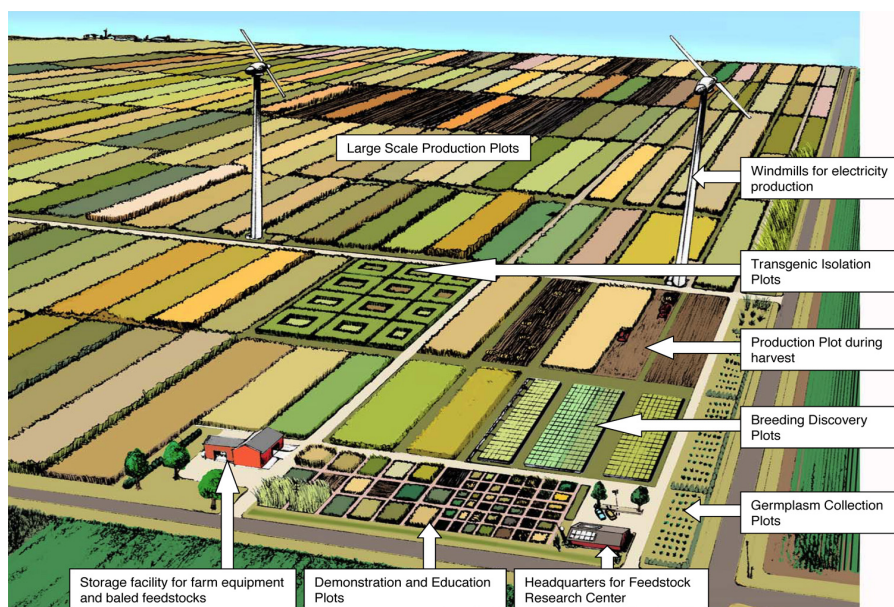
The Computation and Data Management Center will provide a range of services to the institute, ranging from maintenance of the network to the development of specialist applications to support the research laboratories. All of the research programs in EBI will be integrated through the use of an institute-wide electronic recordkeeping system that will archive experimental results in readily accessible databases, provide unambiguous identification and storage locations for all reagents and biological materials, and maintain inventories, network instruments, and related matters. The computer services group will also provide access to electronic journals and information resources (available from UCB) and provide access and training on commercially available software. The group will also have database development capabilities to develop specialized database and analysis tools as necessary. The group will also provide regular in-house workshops on the use of computing resources and consulting for individual users with special software or other computing needs. Because several of the research laboratories within EBI will have strong scientific computing environments, the Computation and Data Management Center will be complementary to those groups.

SYNTHETIC BIOLOGY CENTER

Center Director: *Jay Keasling (UCB/LBNL)*

Synthetic biology is the design and construction of new biological entities — such as enzymes, genetic circuits, and cells — or the redesign of existing biological systems. Synthetic biology builds on advances in molecular, cell, and systems biology and seeks to transform biology in the same way that synthesis transformed chemistry and integrated circuit design transformed computing. Just as engineers now design integrated circuits based on known physical properties of materials and then fabricate functioning circuits and entire processors (with relatively high reliability), synthetic biologists will soon design and fabricate biological entities to accomplish a particular task. To make this happen, biological materials properties (gene sequences, protein properties, natural genetic circuit design) must be formulated into a set of design rules that can then be used to engineer new biological entities.

Synthetic biology is a core function with the EBI. Synthetic biology will provide gene expression control devices for altering biomass synthesis in plants, for producing enzymes needed for lignocellulose depolymerization, and for controlling the production of fuels synthesis and sugar utilization in microorganisms. The Synthetic Biology Center within EBI will design these genetic control elements and characterize them in the detail necessary for engineering a particular function in an organism. These parts and devices will be offered to all EBI investigators on an as-needed basis. In addition to the core function in supplying parts and devices, the Synthetic Biology Center will undertake the science and engineering needed for the future development of parts and devices: composition, isolation, robustness, reproducibility, etc.



Sketch of part of the 340 acre Open-Air Feedstock RD&D Lab.

OPEN-AIR FEEDSTOCK RESEARCH, DEVELOPMENT, AND DEMONSTRATION CENTER

Center Director: Steve Long (UIUC)

Six hundred forty acres within the 4,000 acres of UIUC's South Farms, immediately adjacent to campus, has been designated the University's "Energy Farm." Three state-of-the-art 400 ft windmills are currently being erected on this land—at a cost of \$6 million, these will provide 12M kWh per year or 3% of campus electricity use. The state-of-the-art zero-odor swine facility is being constructed adjacent and will feed a methane generation plant. An area of 340 acres within the Energy Farm, incorporating current large scale *Miscanthus* and switchgrass trials and germplasm collections, will become the "EBC Open-Air Feedstock Research, Development, and Demonstration Center." More acreage adjacent to this land will be available, if needed.

This Center will be the flagship field site for agronomic trials of feedstock crops, germplasm evaluation, propagation, planting, chemical applications, harvesting tests, and as a testbed for farm equipment development. It will include isolation plots for testing on new transgenics and for disease-resistance testing. Research on environmental impacts and sustainability will be incorporated. The fields will be fully instrumented with sensors to monitor a wide range of environmental parameters and processes including solar energy interception, net CO₂ and water exchange, soil moisture, growth (via 3-d imaging), photosynthetic efficiency via reflectance measurement of the photosynthetic reflectance index, and microclimate. These will be linked wirelessly to the Interpretive Center and to campus.

The large amounts of data generated will be handled in established databases on the supercomputers in the National Center for Supercomputing Applications (NCSA) on campus. The germplasm collections of perennial grass biofuel crops, and demonstration plots of all major biomass crops for teaching and extension education, are included. The demonstration plots will be accessed via a 1500 gsf Interpretive Center that will include a seminar hall with projection and offices for the lab manager. The building will incorporate roof solar panels and be built to carbon-neutral specification. Web access video cameras will allow remote monitoring for researchers and educational institutions, on and off campus. The Energy Farm will therefore display how different renewable

options may all operate within a single farm—in particular, how perennial biomass crops, which require far fewer farm operations than corn and soybean, are particularly compatible with windmills.

Socio-Economic Systems Program

A major challenge in making the transition to sustainable energy is the integration of individual technical solutions into an energy system that is consistent with natural cycles, the economy, society, transportation networks, the power grid, and urban infrastructures. Four key areas are critically important in providing an integrated and systems-oriented approach to the transition towards sustainable biofuels production and use.

NEXT-GENERATION ASSESSMENT LABORATORY

Lead Investigator (I): *Daniel M. Kammen (UCB)*

Collaborators: *Ronald Cohen (UCB/LBNL), Alex Farrell (UCB/LBNL), Allan Goldstein (UCB/LBNL), Stephen Long (UIUC), Jürgen Scheffran (UIUC), Margaret Torn (UCB/LBNL)*

The introduction of biofuels will have a significant impact on energy, agricultural and food systems, and the environment. To address these challenges, a new framework for assessing the social and environmental implications of biofuels is needed, one that uses the best available tools and methods from life-cycle assessment (LCA), fuel-cycle analysis, computer-based systems analysis, cost estimation, multicriteria decision-making, sustainability science, and environmental impact assessment. We will expand an existing LCA integrated with an economic model and complementary components, including primary environmental impacts, in conjunction with equilibrium analysis to account for co-product credits. Within this framework we will develop management techniques to measure, track, and manage the life-cycle environmental effects (such as net greenhouse gas emissions) of each production pathway. An interdisciplinary and cross-fertilizing approach will integrate technical, environmental, economic, agricultural, and geo-spatial dimensions into practical solutions for bioenergy supply, in conjunction with the other three project areas. As a starting point, this work can build on the EBAMM model at UC Berkeley, which includes energy and greenhouse gas balances from ethanol production.

BIOFUELS EVALUATION AND ADOPTION LABORATORY

Lead investigator (I): *David Zilberman (UCB)*

Collaborators: *Geoff Hewings (UIUC), Madhu Khanna (UIUC), Anne Silvis (UIUC), Brian Wright (UCB)*

If biofuels are to make a substantial contribution to the world's energy needs, new crops, new cropping practices, and new fuel production technologies will have to be adopted by a wide range of economic actors. We will look at information needs, policies, and incentives to enhance the adoption and strengthen acceptance of new biofuel technologies, including intellectual property rights and fiscal policy that are likely to affect innovation and production. We will undertake empirical field research in the United States, Europe, and selected developing countries (including China, India, and nations in Africa and Latin America) to study the energy, agricultural, and environmental impacts of current and potential biofuels, combining qualitative and quantitative methods to evaluate how sustainable biofuel production can be encouraged and advanced in different contexts. We will evaluate potential costs and environmental implications of different production pathways and barriers that could prevent deployment of each pathway.

BIOFUELS MARKETS AND NETWORKS LABORATORY

Lead investigator (I): Jürgen Scheffran (UIUC)

Collaborators: Michael Hanemann (UCB), Geoff Hewings (UIUC), Madhu Khanna (UIUC), David Zilberman (UCB)

The productivity, cost effectiveness, land use, environmental impacts, and transportation requirements of bio-energy crops will be integrated and modeled in a regional context, linking local, national, and global dimensions of supply and demand. A significant aspect of this work is to examine the allocation of land and other resources among competing alternatives to meet various levels of demand for biofuels. Through exchange with the conceptual and empirical assessments derived in the first two project areas, discussed above, we will study areas where it is appropriate to switch to production of biofuels, based on costs and environmental benefits such as soil carbon sequestration and the optimal mix of feedstock such as corn stover, other agricultural residues, switchgrass, and *Miscanthus*. We will compare two regions in the United States (California and the Midwest) and other parts of the world (Europe, China, Africa). Using appropriate models, and information and decision-support tools, and building on a well-established research infrastructure and instruments in GIS-based spatial and regional economic modeling at UCB and UIUC, we will evaluate the potential role of EBI-developed technologies and develop a regional feedstock supply and distribution network.

SOCIAL INTERACTIONS AND RISKS LABORATORY

Lead investigator (I): Brian Wright (UCB)

Collaborators: Stephen Long (UIUC), Jeff Perloff (UCB), Anne Silvis (UIUC), David Sunding (UCB), David Winickoff (UCB)

A significant investment in the social sciences is crucial for successful innovation and adoption of alternative energies. To address potential concerns, a mix of information, participation, and compensation is appropriate. Citizens need relevant information at an early stage, must have the chance to participate in the planning and decision-making process, and must have compensatory mechanisms for costs and risks. We will consider design of institutions and policies to mitigate some of the negative impacts. This research will profit from paying significant attention to the evolving regulatory framework and societal response to genetically modified organisms at both the domestic and international level. Included will be work on the public understanding of biofuel technologies and the modeling of social adoption in different political contexts, associating with the work undertaken in the second and third project areas discussed above.

Research Facilities and Resources for EBI Laboratories

	Carver Biotechnology Center (UIUC)	Morrow Plots (UIUC)	Open-Air Feedstock R&D Center, (UIUC) USDA Western Regional Research Laboratory, Phylochip Development Lab (LBNL)	Off-road Agricultural Vehicle Development Facility, John Deere Collaborative (UIUC)	Integrated Bioprocessing & Research Laboratory (UIUC)	Molecular Foundry (LBNL), QB3 Biomolecular Nanofabrication Center (UCB)	National Center for Electron Microscopy (LBNL)
Feedstock Development							
Feedstock Production			X	X			
Feedstock Genetics & Plant Breeding	X		X				
Biomass Engineering		X				X	X
Lignin						X	X
Biotic Stress			X				
Environmental Impact & Sustainability Assessment	X	X	X				
Harvesting Transport & Storage			X	X			
Biomass Depolymerization							
Feedstock Pretreatment					X	X	X
Enzyme Discovery					X		
Enzyme Structure & Function					X	X	X
Enzyme Evolution & Engineering					X	X	X
Integrated Bioprocessing					X	X	
Biofuel Chemistry							
Biofuels Production							
Pathway Engineering							
Systems Biology							
Host Engineering					X		
Fossil Fuel Bioprocessing & Carbon Sequestration							
Fossil Fuel Bioprocessing							
Microbial Enhanced Oil Recovery							
Biological Carbon Sequestration							
Discovery & Development Support Centers							
Chemistry						X	
Imaging							X
Computation & Data Management						X	
Synthetic Biology						X	
Open-Air Feedstock R&D							

QB3 NMR Facility (UCB)	Structural Biology Program (LBNL)	Advance Light Source (LBNL)	NCSA (UIUC), NERSC (LBNL), Computational Biology Program (UCB)	Synthetic Biology Engineering Research Center, (UCB) Berkeley Institute for Synthetic Biology (UCB)	BP Catalysis Program (UCB)	Virtual Institute for Microbial Stress & Survival (VIMSS) (LBNL), Institute Genomic Biology Biocomplexity Group (UIUC), Institute for Genomic Biology (UIUC)	Joint Genome Institute (LBNL)	Center for Computational Geosciences (UIUC), Center for Environmental Biotechnology (UCB), Center for Isotope Geochemistry (UCB), Berkeley Genomes to Ecosystem Model Mesocosm Facility (UCB), TOUGH (UIUC)
							X	
X	X			X				
X				X				
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			X			X	X	
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X		X						
			X					
			X			X	X	
			X	X		X	X	

EDUCATION

Education, outreach, and training are key to development of the human and social capital required for an initiative the magnitude of the EBI. UCB, LBNL, and UIUC have exceptionally strong undergraduate, graduate, and postdoctoral training programs, as well as nationally recognized K–12 science outreach programs such as those of the Lawrence Hall of Science and education extension programs at UCB and UIUC. As a result, our partnership can offer a large number and wide variety of extraordinary educational program options to the EBI. We propose to:

- Provide BP participants broad access to the educational and intellectual resources available at UCB, LBNL, and UIUC
- Educate a new generation of scientists (postdoctoral, Ph.D., and baccalaureate-level) well equipped and highly motivated to bring innovative approaches and collaborative scientific efforts to solve global energy challenges
- Educate the general public about the benefits of EBI research and technology advances
- Educate public policy students and policy makers about issues surrounding the scientific advances and challenges addressed by the EBI's programs
- Participate in established extension activities at both campuses targeting the greater agricultural community
- Educate K–12 students about the opportunity and excitement provided by a career in science and engineering dedicated to solving global energy challenges

The EBI will provide innovation at all levels of training. Curriculum and program content will continually evolve as research advances and technology innovation occurs. The education program will include components to reach and meet the needs of the various constituent populations, including graduate and undergraduate students, women and underrepresented minorities, the K–12 community, the community-college population, and the general biological sciences and engineering research communities.

BP Scientists' and Engineers', Participation in Academic Life. UCB, LBNL, and UIUC will provide BP EBI participants with access to the vast resources and lively intellectual interactions available at each partner institution, including:

- Participation in the development, design, and delivery of courses and seminar series
- Opportunities to co-mentor graduate students (with a faculty member)
- Opportunities to mentor undergraduate students and postdoctoral fellows
- Access to library and research resources
- Invitations to participate in all EBI laboratory and program research meetings
- Opportunities to audit undergraduate and graduate courses of interest
- Participation in outreach and educational activities targeting K–16 audiences, including UCB, LBNL, and UIUC programs directed at increasing diversity and interest in pursuing careers in science and engineering
- Opportunities to provide leadership and guidance to energy-based graduate and undergraduate student groups and activities

Graduate Education. The goal of a graduate education program is to prepare students for careers in academia, industry, government, or non-government organizations. Key graduate education components we expect to be developed under the EBI include:

- New graduate courses
- Opportunities for graduate students to rotate among laboratories across the disciplines and traditional department/college barriers
- UCB Designated Emphasis (DE) and UIUC Certificate in Energy Science and Technology
- Seminar series in various areas related to the EBI mission
- Cross-institutional laboratory rotations
- Programs to support entrepreneurial student interests in bioenergy

The EBI provides an opportunity to develop a common framework to organize course offerings. It is important to identify the skills and knowledge that must be mastered by students interested in this area of research and discovery, and to develop a curriculum that supports this knowledge building. Some of the fundamentals will be covered in established, traditional courses, while other specific courses covering current state-of-the-art issues in the fields will need to be developed. Existing UCB and UIUC course offerings are detailed in Appendix 4, p. 44. The EBI's research areas include evolving fields such as synthetic biology, and as such, we anticipate that the curriculum and academic program development will continue to develop over time. We will develop a map that will serve as a starting point for creating a strong foundation for future development. We will take advantage of technology such as webcasting to make curriculum available to partner institutions and to a broader audience.

To provide a forum and meeting place for multidisciplinary discussions in an informal setting — and thereby promote awareness of ongoing research in other disciplines and encourage collaborations — the EBI will initiate and sponsor a student-run EBI public seminar series. Seminar speakers will include distinguished national scientists. The series will be widely publicized to faculty, graduate students, postdoctoral fellows, and the greater science community. Speakers will be requested to share slides so that they can be made available on EBI's website. Seminars will be videotaped and made available to the broader community through webstreaming and videosharing, which will provide broad access to these state-of-the-art talks.

Many students believe that energy and climate change is the most important problem (and opportunity) of their generation. The next several decades are a critical period for developing sustainable, carbon-neutral sources of energy that reduce the threat of global warming, strengthen our energy security, and foster economic growth and the creation of high-wage jobs. UCB's recently launched "Designated Emphasis" (DE) in Energy Science and Technology will prepare graduate students in science and engineering to tackle this challenge. By allowing graduate students in 11 affiliated Ph.D. programs to specialize in energy science and technology, the DE will provide training solutions to the multidisciplinary challenges of the EBI research program. A number of the designated EBI investigators are members of the DE, and more are expected to join. Graduate students supported by the EBI will be encouraged to participate in the DE. At UIUC, a similar course of study will be provided through a graduate certificate program, the equivalent to a DE. UIUC is also interested in developing a multi-track interdisciplinary master's degree in bioenergy research, and recently launched a new Ph.D. program in bioenergy feedstock generation and processing that graduated its first class last year. New courses related to bioenergy and biofuels will be developed at both institutions to support the continued evolution of these programs.

Graduate students will be provided the opportunity to participate in a mutual exchange of graduate students between the UCB and the UIUC to broaden training and ensure integration of training in the core research areas of the project (feedstock development, biomass depolymerization, biofuels production, fuel

bioprocessing and carbon sequestration, socio-economic systems, discovery, and development).

The EBI will develop a cadre of scientists and engineers with an understanding of key business concepts and energy markets, meaningful industry experience, and the opportunity to work with M.B.A. students developing business plans. To accomplish this goal, the EBI will build on the Management of Technology Program at UCB. This certificate program allows business, science, and engineering students to specialize in the Management of Technology by taking courses such as “Managing the Product Development Process,” “Entrepreneurship,” “Opportunity Recognition,” “Engineering Leadership and Teamwork,” and “Project Management.” These project-oriented courses encourage the formation of multidisciplinary teams that often participate in local, regional, and national business-plan competitions, such as the Haas Business Plan Competition, the Global Social Venture Competition, and the new California Cleantech Open. Participation in this program by BP EBI scientists and engineers will greatly enrich the program’s promise in biofuels areas.

Because of the high level of interest in clean energy, UCB students have proposed creating a Center for Energy Innovation that would strengthen the connections between business, science, and engineering students. The Center would organize and sponsor the development of a new set of courses, such as “Energy, Sustainability, and Business Innovation,” to prepare students to assess the commercial viability of new energy technologies, obtain venture capital and other funding for projects, position and market new energy solutions, and develop productive relationships with partners in industry, the environmental movement, and state, local, federal, and international agencies.

The Berkeley Energy and Resources Collaborative (BERC) is a 135-member organization including students and researchers from science, engineering, business, and LBNL. BERC will organize a large annual student-run conference showcasing EBI research and a speaker series featuring clean-energy entrepreneurs.

Undergraduate Education. UCB graduates more undergraduates who go on to receive Ph.D.s than any other university in the United States. The EBI will offer new courses and research opportunities to stimulate undergraduates at UCB and UIUC to focus on global energy challenges.

To prepare undergraduates for entering a career in industry, or a graduate program, the EBI can enrich the undergraduate experience by sponsoring:

- Undergraduate energy-based student interest groups at UCB and UIUC
- Practical and field-training internships and practica at bioenergy plants and businesses, and farms and feedstock production facilities.
- Wireless network capability in the “Open-air Feedstock Research Development and Demonstration Laboratory” to provide remote acquisition of data and video to facilitate off-site high-school and undergraduate research projects
- New courses
- Undergraduate research opportunities in EBI laboratories
- Undergraduate internships with BP labs worldwide
- Participation in the International Genetically Engineered Machine (iGEM) competition

EBI will sponsor a prize as part of the International Genetically Engineered Machine (iGEM) competition. It will be awarded to student teams who develop parts and devices that are most relevant to biofuels and other energy applications of biotechnology. The prize could be named the “iGEM BP Energy Prize.” Nearly 500 students and their advisors from 15 countries participated in iGEM 2006. The iGEM program brings to undergraduates and participants the type of team-science experience that will be the daily life for researchers in the EBI. EBI

postdoctoral fellows and graduate students will supervise participating student teams and share with them their collaborative experience from the EBI. The competition will provide the EBI an opportunity to recruit the brightest students from across the country to spend the summer at the EBI.

At UIUC, the Environmental Council established the Undergraduate Environmental Fellows Program (EFP) in various fields related to energy and the environment. A number of courses cover issues directly or indirectly related to energy, with great strengths in agricultural and biological engineering, feedstock production, and environmental engineering. For example, the “Plants and Global Change” course, addressing how integrated biological systems may be used to mitigate global change, was one of the first of its kind when launched in the 1990s.

UCB and UIUC Education Extension. The Hatch Act of 1887 established a system of agricultural experiment stations at land-grant universities devoted to mission-oriented research. As part of the land-grant missions of UCB and UIUC, both campuses operate extension education centers, and both are closely linked to the extension services of the national network of land-grant universities. These centers have a long tradition of integration with the agricultural community, serving as an information source and sites for off-campus education. More recently, UIUC Extension developed resources for education within Chicago and East St. Louis that link the rural community to business and industrial opportunities. The EBI will partner with campus programs to transfer relevant EBI knowledge and practical information to the greater agricultural community. The Extension Education service and its national links are critical to diffusing the mission of the EBI and maintaining a dialogue with the people and landowners whose support and understanding will be crucial to the development of a large biofuel economy.

K–12 Education. UCB, LBNL, and UIUC attract some of the world’s best undergraduate and graduate students and postdoctoral fellows. The EBI will have the opportunity to work with the Lawrence Hall of Science to develop an exceptional K–12 outreach program through the development of K–12 curriculum modules, public exhibits, and unique educational programs to deliver knowledge linked to the research occurring at the EBI. Additional K–12 components might include:

- *Visiting lectures.* Participating faculty and graduate students will present brief lectures at participating high schools and community colleges. Lecture topics will be selected specifically to spark interest in science by addressing recent developments and the impact of science on the world.
- *Teacher training.* K–12 teachers will participate in a one-week summer “job shadowing” experience with EBI researchers participating in discussions regarding emerging findings and technology in science.
- *A Day in Science.* This full-day program will invite high school and community college students to visit and shadow a current student as they work in the lab and attend class. Students will be able to meet with the supervising researcher, become acquainted with a college campus, and explore the educational and career opportunities that exist in science.
- *Summer internships.* Community college and high school students will gain practical experience working on-site with graduate students and researchers in EBI laboratories. This program will leverage LBNL’s high school research opportunity program.

Broader Education Efforts. EBI will strive to become the world's foremost program in bioenergy. As such, it will offer opportunities to educate scientists around the world in this cutting-edge area through a variety of possible ventures: EBI publications in high-profile, peer-reviewed journals; a short, intensive summer course; an annual symposium and regular seminars; and an electronic newsletter and press releases describing important discoveries, the achievement of critical milestones, and the development and availability of new tools and technologies. These efforts are outlined in greater detail in Communications on page 65.

To meet the training needs of industrial and academic scientists and engineers, the EBI might provide a weeklong continuing-education summer course on targeted topics. The course would be open to all Ph.D. researchers, postdoctoral fellows, and graduate students, in the appropriate academic and industry research communities. EBI affiliates would teach the courses, but leading experts from other institutions would be invited to present lectures as well. Courses would have both hands-on and informal seminar components. The EBI could also develop a sophisticated course program for distributed and distance learning, as part of a Web-based virtual bioscience lab and a publicly accessible information base.

COMMUNICATIONS

Communication systems and processes will be established immediately. The communications plan will include:

- A “telepresence” meeting room
- A public relations plan
- An annual retreat
- Specialized workshops
- An annual national symposium
- A public and internal website
- E-room management
- A desktop videoconferencing system
- Periodic newsletters
- Public and internal listservs
- An annual report

“Telepresence” Meeting Room

A state-of-the-art, “telepresence” meeting room will be constructed at both UCB and UIUC to support meetings between researchers at the two locations. These meeting rooms provide nearly the same quality of interaction as in-person meetings. Cisco’s TelePresence product will be the centerpiece of these facilities, using life-size, ultra-high definition video displays and spatially discrete audio to create a virtual meeting room encompassing both locations. This full-immersion environment provides a near real-time experience of a live, face-to-face meeting around a “virtual” meeting table. Cisco’s commitment to the EBI, as well as UCB’s long-standing, close relationship with Cisco’s Higher Education support team, will help to ensure the success of the telepresence meeting room. The commitment to this project has been formalized by a letter from Cisco Systems, a copy of which can be found in Appendix 5, p. 48.

An Access Grid Node will be used to augment the electronic collaboration tools described in the previous paragraph. Access Grid (AG) can be used for large-scale distributed meetings, collaborative work sessions, seminars, lectures, tutorials, and training, and will bridge the gap between the desktop videoconferencing and the telepresence meeting room systems described above. Scientists at multiple sites can simultaneously share scientific instruments, conduct experiments, and manipulate the same data sets and visual simulations across the Web in real time, while talking back and forth. Additionally, because AG has already gained wide acceptance among scientists and engineers, and because AG nodes already exist at many sites (including UCB and UIUC), AG will provide EBI scientists with the ability to collaborate with other scientists and researchers worldwide.

The impact of integrating TelePresence, the Access Grid, and desktop videoconferencing, when combined with ultrahigh bandwidth fiber connections between UIUC and UCB, will be a level of seamless collaboration not previously possible between researchers in widely separated locations. In addition, the TelePresence and Access Grid architecture can be extended to a BP research facility in the UK or another location, providing collaboration opportunities for external BP researchers to work directly with those located at the UCB campus.

Public Relations Plan

The EBI will develop and implement a strategic public relations plan to ensure that the EBI maintains national and international visibility as the world's premier energy research institute. The EBI will work in collaboration with and build on the resources provided by UCB, LBNL, UIUC, and BP's public relations capabilities.

Annual Retreat and Workshops

Each year, prior to developing the annual program plan, the EBI will hold an annual retreat. All EBI investigators, graduate students, postdoctoral fellows, and scientists will participate in the event. The retreat will serve a number of purposes, including building a strong sense of intellectual community, supporting scientific exchange, and ensuring broad participation in both long- and short-term planning. Throughout the year, workshops will be organized on specific topics based on scientific needs and progress. The format of the workshops and the invited participants will depend on the topic.

Annual National Symposium

Following submission of the Annual Report to the Governance Board, the EBI will coordinate an annual symposium on select topics, inviting scientists from around the world to participate. A possible format for the symposium will be one-and-a-half days in length and include speakers representing the EBI, industry scientists, scientists from governmental agencies, and renowned scientists from around the world. Attendees will be selected based on research expertise and research-area relevance to ensure a diversity of representation from academia, industry, and government agencies.

Public and Internal Website / E-Room Management

The EBI will make use of technological advances to support a robust communications plan and create an environment that makes communication across distances and on demand as easy as possible. EBI participants and the academic, research, industry, and public communities will access information through the EBI website. The website will be developed for both external and internal audiences. A password-protected intranet will be developed for Institute participants to allow for the sharing of internal Institute information and communications. An E-room was established for the development of this proposal, allowing for easy filesharing and streamlined electronic communications. The EBI will utilize this E-room to support EBI research collaboration.

Desktop Videoconferencing System

All researchers and staff will have access to each other through desktop videoconferencing using an efficient, powerful, and easy-to-use system that runs on all major computer platforms. The system is Web-based, allows multiple points of contact to participate in a videoconference, and provides real-time document sharing and editing.

Periodic Newsletter / Public and Internal Listservs

Although the website will provide easy access to EBI information, tools, and research results, it requires active participation on the part of those seeking information. To ensure that EBI news, including research advances and tools development, is broadly disseminated, the EBI will distribute a monthly or quarterly newsletter. The

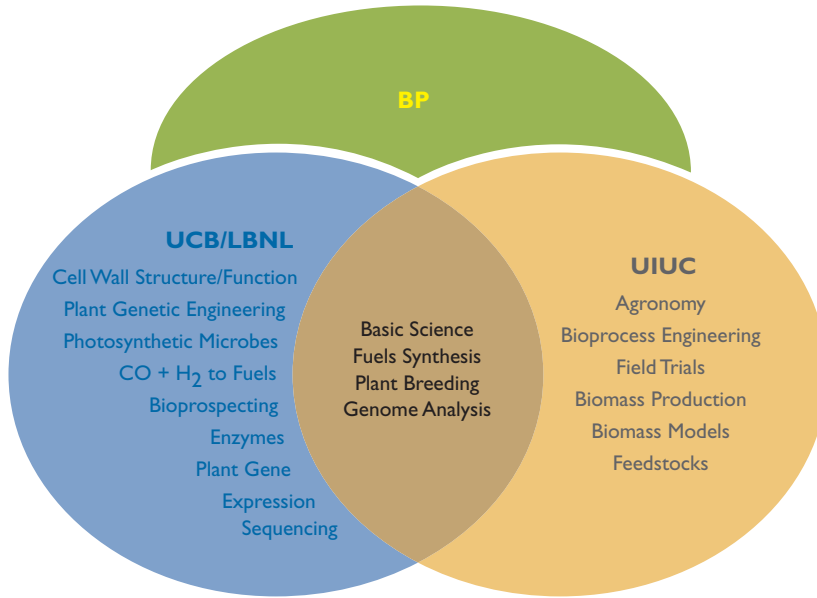
Institute will develop and maintain a list of electronic addresses and mailing addresses for public and internal listservs. The newsletter will be sent in pdf format to those on the electronic list, as well as in hardcopy to those who prefer this means of delivery and to appropriate academic and research institutions.

Annual Report

A public annual report will be prepared each year providing a status report on all EBI activities. The comprehensive report will include updates on research, technology advancement, and education and training. The Executive Committee will develop an internal annual report and work plan that will include detailed plans and goals for the upcoming year, and will serve as a basis for the Governance Board's decision-making processes.

PLACEMENT OF WORK WITH COLLABORATING INSTITUTIONS

Capabilities of the Lawrence Berkeley National Laboratory (LBNL) and the University of Illinois at Urbana-Champaign (UIUC) will be used extensively to accomplish the goals of the proposed new Institute. Both institutions provide significant and complementary expertise to the project. The Venn diagram below shows the contributions of the partners in this project.



Partner contributions to the EBI.

Lawrence Berkeley National Laboratory (LBNL)

Lawrence Berkeley National Laboratory (LBNL) has been a leader in science and engineering research for more than 70 years. Located on a 200-acre site in the hills above UC Berkeley's campus, and overlooking the San Francisco Bay, LBNL holds the distinction of being the oldest of the U.S. Department of Energy's National Laboratories. LBNL is managed by the University of California, operating with an annual budget of more than \$500 million (FY 2004) and a staff of about 3,800 employees, including more than 500 students.

LBNL was founded in 1931 by Ernest Orlando Lawrence, winner of the 1939 Nobel Prize in Physics for his invention of the cyclotron, a circular particle accelerator that opened the door to high-energy physics. It was Lawrence's belief that scientific research is best done through teams of individuals with different fields of expertise, working together. His teamwork concept is an LBNL legacy that has yielded rich dividends in basic knowledge and applied technology, and a profusion of awards. Associated with LBNL are 11 Nobel laureates, 59 members of the National Academy of Sciences, 19 members of the National Academy of Engineering, and three members of the Institute of Medicine.

LBNL conducts unclassified research across a wide range of scientific disciplines, with key efforts in fundamental studies of the universe, quantitative biology, nanoscience, new energy systems and environmental solutions, and the use of integrated computing as a tool for discovery. It is organized into 17 scientific divisions and hosts four DOE national user facilities. These facilities include the Joint Genome Institute, the National Energy

Research Supercomputing Center, the Advanced Light Source, and the Molecular Foundry, which are described in detail in the Buildings and Laboratory Facilities section.

LBNL is unique among the DOE national laboratories in that it began on the university campus, and currently, more than 250 principal investigators (PIs) at LBNL are full-time professors at UCB. That association has deeply shaped LBNL's policies, procedures, and culture. There is open access between the two institutions, and constraints on IP, procurement, security, and use are minimal, providing LBNL with the most transparent research environment in the national laboratory system. All LBNL employees are employees of the University of California.

University of Illinois at Urbana-Champaign (UIUC)

UIUC contributes extensive expertise, facilities, and personnel in the agronomy of biomass production, plant breeding for biomass production, and biomass processing. The campus has extensive field plots, greenhouses, and plant growth chambers on site. UIUC is home to a decade-long project on novel approaches to biomass production and is recognized for its leadership in fermentation processes for biofuel production.

As indicated in the organizational structure (page 8), the EBI will have a deputy director in residence at UIUC to oversee the non-proprietary work of that institution's subcontracts. Reporting to the EBI director, the deputy director will ensure that research carried out at UIUC is well integrated with activities across the EBI. Program directors will be charged with coordinating the work at the two sites. UIUC will also establish a small working site for the EBI proprietary component.

As a premier public university, UIUC has a culture of research innovation that closely aligns with the scientific culture at UCB and at LBNL. All three institutions have a demonstrated ability to interact seamlessly to jointly develop and manage research and its products. For example, in the field of microelectronics, UIUC and UCB have collaborated closely for nearly 10 years on the Gigascale Systems Research Center (GSRC). This \$7 million project is a public-private partnership managed by UCB that addresses the current limits of the International Technology Roadmap for Semiconductors (ITRS) in the areas of design and testing. The GSRC research collaboration involves six major U.S. universities, with UIUC as a key partner.

INTERACTION WITH BIOTECHNOLOGY AND INNOVATION ECOSYSTEMS

UCB/LBNL and Northern California

Northern California is the ideal location for the Energy Biosciences Institute (EBI). It has the largest concentration of biotechnology and high-technology companies in the world, and it is poised to become the hub for renewable energy research.

Biotechnology Sector. The San Francisco Bay Area is the premier biotechnology region in the world with 900 companies, 90,000 workers, 393 marketed products, and 400 products in Phase II or Phase III clinical trials. The area features four major research universities with research budgets of over \$500 million each and strong life sciences programs: UCB, UC Davis, UCSF, and Stanford.

This vibrant biotechnology sector creates a variety of opportunities. Given that many entrepreneurial UCB faculty and students and LBNL scientists have founded scores of companies, most within a 35-mile radius of the campus, UCB and LBNL can help mobilize the intellectual and technological resources of the region to make the EBI a success. EBI scientists will have close relationships with many biotech executives and industry researchers. Through workshops and meetings, the EBI will be able to identify companies that may have new ideas or unique capabilities. The EBI's Technology Transfer Director will act as an initial point of contact for companies that believe that they have something to contribute.

High-Technology Sector. The EBI will also be able to draw on Silicon Valley's unparalleled strengths in other technologies, such as IT, microsystems, and nanotechnology. The Bay Area's high-tech sector claims 13,100 companies and 371,509 employees. It has generated more than 10% of the nation's patents and attracts more than 25% of the venture capital of all sectors (and almost half of the venture capital nationwide in computers, peripherals, networking equipment, and semiconductors / semiconductor manufacturing equipment). The value-added per employee, a measure of productivity, is two and one-half times higher in Silicon Valley than it is nationally.

Doing Business with UCB. UCB actively encourages collaborative and sponsored research with industry, consistent with our educational mission and the principles of academic freedom. These partnerships give our faculty and students new ideas, increase the commercial impact of our research, and prepare our students for non-academic careers. In the last two years alone, UCB has entered into 285 new material transfer agreements with industry, 160 new sponsored-research and collaboration agreements, and 37 new affiliate program contracts to support research by private industry on the UCB campus. UCB has recently been described as "one of five universities you can do business with" by Inc. Magazine (Feb. 2006) (Appendix 6.1, p. 50). The University has a number of master agreements with companies that streamline how it contracts for sponsored research, or obtains vital materials or other research tools to support campus research. We are confident that contracts with industry providers can be agreed to in support of EBI research.

Business Community & Clean Energy. The leadership of Northern California's business community has made clean energy a top priority. Leading venture capitalists such as Khosla Ventures and Kleiner Perkins are investing heavily in biofuels and other clean-energy startups. PG&E (the utility serving Northern California) already receives 56% of its energy from carbon-neutral sources, and is committed to empowering

consumers to become carbon-neutral. Furthermore, Governor Schwarzenegger and the California State Legislature have taken bold and decisive action to tackle climate change. The recently passed AB32 requires the State to reduce emissions of greenhouse gases by 25% by 2020. An Executive Order signed by the Governor calls for an 80% reduction by 2050. The state's bioenergy action plan details specific steps that agencies will take to maximize the contribution that bioenergy can make to the state's environmental and climate-change goals.

In a letter to BP, venture capitalists and senior industry executives pledged to support the EBI (Appendix 1.4, p. 7) by:

- Coinvesting with BP in spin-offs from the EBI, and investing in other companies that are needed to strengthen the biofuels value chain
- Attracting additional industry partners, consistent with BP's corporate interests
- Identifying unique capabilities in industry that could be important assets to the EBI, such as genetic engineering, protein analysis, expression analysis, pathway engineering, and plant breeding
- Mentoring EBI students and postdoctoral researchers who are interested in pursuing careers in the energy biotechnology and biofuels industry
- Advocating for federal and State policies that support the EBI, and more broadly, that foster research, development, demonstration, and deployment of biofuels

UCB and LBNL technologies have been the basis for at least 116 licensed start-up companies; twenty of them coming from LBNL. Although we commit to keep the terms of the agreements confidential, companies that have given permission to be identified are included in Appendix 6.3, p. 52.

UIUC and the Chicago Area

UIUC has a similarly strong set of relationships with the companies that are leading the technological revolution in agriculture. At UIUC, many technology start-ups and spin-offs have been created from campus-based research, a number of which have been purchased by larger companies such as Motorola, Intel, Microsoft, Sundstrand, and others. UIUC also boasts strong links to the powerful Midwest manufacturing, agribusiness, transportation, and technology sectors.

UIUC's participation brings with it significant involvement with Chicago and other regional economic hubs across many industries, from financial markets and service sectors to technology and manufacturing companies, as well as with Illinois Venture, LLC, a venture fund investing heavily in information technology and software, life sciences, basic engineering, and physical sciences.

EBI AGREEMENTS

UCB will negotiate and execute a master agreement with BP that will address the provisions articulated in the EBI RFP. There will be a single, “master” collaboration agreement between BP and UCB as the prime contractor. UCB will subcontract funding to LBNL and UIUC. The master agreement terms will be passed along (i.e., flowed down) to the subcontractors. UCB will also have inter-institutional agreements with each of the subcontractors on the mechanics of IP management and licensing, and will thus act as the single point of contact for BP on all IP matters.

The process to initiate an EBI research project will be as streamlined as possible. The parties will complete a simple “Research Project Description” (“RPD”) that documents the project personnel, funding for the collaboration, project duration, project scope of work, and any special items to be considered (such as the use of proprietary materials, or “outside” resources). Each RPD will be signed by the participating institutional partners and will simply invoke the terms of the master agreement, obviating the need to negotiate or sign any new contracts. A draft RPD is included in Appendix 2.1, p. 23.

UCB has successfully managed similar agreements with industry. For example, UCB has long-term “Open Collaborative Research Agreements” with Intel and with Yahoo! governing research collaborations in Intel and Yahoo! satellite research “labs” that are located close to campus in commercial, leased space (see Intel agreement in Appendix 2.1, p. 13). In addition, UCB has entered into long-term research collaborations in which general “Guidelines for Research Interactions” between a corporate research sponsor and the campus have been developed, such as in Appendix 2.2, p. 27. Moreover, template confidentiality agreements and material transfer agreements have been negotiated in advance in support of multi-year sponsored research agreements (see Appendices 2.3, p. 31 and 2.4, p. 32).

We are confident that the lease and research contracts will be consummated in a timely and efficient manner. A lead negotiator will be responsible for this at UCB and will coordinate with all subcontractors, with the UC Office of the President, with internal and external counsel, and with other stakeholders.

INTELLECTUAL PROPERTY

UCB, LBNL, and UIUC share BP’s vision of creating robust and long-term technological solutions to global energy challenges. At the heart of this vision is a structure for the EBI that positions our academic institutions as the fundamental science core of an energy technology commercialization scheme, performing research that will be published in the open literature by UCB, LBNL, and UIUC researchers. This basic research component will engender applied research by BP scientists and engineers in the EBI through such activities as field testing and demonstration projects.

In support of this shared vision for the EBI, our approach to intellectual property (IP) issues recognizes the Institute’s two major organizational components:

- *A Proprietary Research Component* staffed and directed by BP researchers
- *An Open Research Component* utilizing UCB, LBNL, and UIUC researchers and facilities

The proprietary component will be carried out by BP personnel in a central Berkeley campus location under an operating lease. BP personnel will engage in proprietary research in the leased space and will have no obligation to publish research performed in the leased space. UCB, LBNL, and UIUC research personnel should be excluded entirely from the space in the performance of their university activities.

Research performed by UCB, LBNL, and UIUC members of the EBI in Host Institution space will have no restrictions on publication (other than a review period for BP), will support graduate student and postdoctoral fellow training, and will occur in an open, academic environment.

IP Ownership — “Yours, Mine, and Ours”

Our approach to IP ownership assumes that inventorship is based on U.S. patent law and that:

- BP will own inventions made solely by their personnel in BP’s leased space
- UCB, LBNL, and UIUC will solely own inventions made solely by their personnel in their own space
- Inventions naming at least one inventor from BP and at least one inventor from the partner institutions will be jointly owned
- BP, UCB, LBNL, and UIUC will jointly own inventions made by BP researchers using facilities or resources of the partner institutions (except when inventions are made in user facilities under “fee for services contracts” — publication of such inventions will not be restricted)

All rights in data will be reserved, and U.S. government rights will be reserved: a) for inventions arising from U.S. federal funding at the UCB and UIUC campuses, and b) for all inventions owned by LBNL. Some of the terms above deviate from standard policy for UCB, LBNL, and UIUC and require exceptions to policy in order to be implemented. Our three partnering institutions are willing to seek exceptions and to administer the exceptional terms as a demonstration of our commitment to inventing technological solutions for public benefit; furthermore, we assume that BP will agree that rigorous management of all EBI-generated IP rights will be required to allow the public institution partners to uphold their missions and integrity as stewards of public property.

Licenses to Commercialize EBI Innovations

We will commit to a unified approach to the granting of licenses to innovations arising from EBI research projects as follows:

- a) For inventions made by UCB, LBNL, or UIUC under a project that is fully funded by BP, BP will be granted a nonexclusive, royalty-free license in BP's areas of interest to UCB, LBNL, or UIUC's solely owned inventions provided that:
 - i. to ensure public benefit, such license will include an obligation by BP to diligently pursue commercialization of the licensed invention
 - ii. the owner(s) will have no obligation to obtain patent rights unless it has a commitment from at least one licensee to underwrite the patent costs
- b) The mechanism by which BP may obtain exclusive license rights to:
 - i. UCB's, LBNL's or UIUC's sole interest in a sole invention
 - ii. UCB's, LBNL's or UIUC's interest in a jointly owned invention

developed in EBI projects that are fully funded by BP is as follows. BP will have an exclusive, time-limited, first right to exercise a pre-defined option to obtain an exclusive license that includes capped fees and/or royalty ranges in the fields where it is possible to estimate those ranges. The option agreement defines the terms of an exclusive license agreement but is useful to BP because it grants BP relatively long periods of time (successive one-year terms, as long as BP is diligent during the option periods in evaluating the commercial potential of the inventions) in which to evaluate the commercial potential of a given technology without having to commit, outright, to the terms of an exclusive license before the technology has been proven. The ongoing, 10-year, \$10 million sponsored research agreement between BP and UCB's College of Chemistry (on conversion of natural gas to fuels and chemicals) provides one example of how this mechanism works. In the first six years of this project, the supported laboratories have produced six patent portfolios to which BP has obtained exclusive option rights. BP has designated the geographies worldwide where patents have been filed, and is underwriting those costs. The project has been mutually beneficial, establishes parameters for both parties (on future valuation), and allows BP prolonged periods of evaluation to determine if and when it wishes to obtain an exclusive commercial license.
- c) BP has also requested license rights to background intellectual property. Such rights could be granted in commercial licenses on a case-by-case basis when they are not encumbered by prior or other obligations, do not sweep-in rights of researchers or laboratories that are not part of the relevant EBI project, and whose inventors agree to such license grants. Rights to background IP arising from non-BP funding would not be subject to foreground IP license parameters described in paragraphs a) or b) above. Moreover, background IP owned by third parties cannot be included in commercial licenses referred to above without the written consent of a third party.

III. QUALIFICATIONS (MISSION-DRIVEN INITIATIVES)

UCB, LBNL, and UIUC have a long history of managing mission-driven initiatives. Examples include several major research projects (the discovery of the 14 transuranic elements, the Cosmic X-ray Background Explorer, the discovery of Dark Energy, and the discovery of photosynthesis); the development of major user facilities (the Advanced Light Source, the Joint Genome Institute, and the SoyFACE Project) that have been the foundation for many subsequent scientific discoveries (crystal structures of many enzymes including RNA polymerase and the ribosome, sequences of three human chromosomes, and many microbial genomes); and several biotechnology-related or energy-related projects (the Helios and artemisinin projects, CITRIS, SynBERC, the codling moth control programs, and extreme ultraviolet lithography). In the case of the user facilities, the work involved time-sensitive milestones, and in all cases the projects were completed on or ahead of schedule and at or below projected costs. With respect to the research projects, interdisciplinary teams of individuals were involved to complete milestones — coordination was critical for project completion. Finally, several milestone-driven projects have been undertaken in collaboration with industry, where collaboration among university and industry scientists was critical for successful project completion. A few of these projects are listed below.

DISCOVERY OF 14 ELEMENTS

UCB and LBNL scientific teams developed many of the techniques for discovering new heavy elements. A team of accelerator scientists, nuclear physicists, and chemists led by Glen Seaborg, Edwin McMillan (Laboratory director from 1958 to 1971), and Al Giorsio discovered 14 transuranic elements, later recognized by the 1951 Chemistry Nobel Prize to Seaborg and McMillan. The skilled and creative application of the accelerators, the development of advanced detector and spectrometer systems, and the careful selection of the appropriate nuclear reaction species were essential for success.

DISCOVERY OF “SEEDS OF THE UNIVERSE”: COSMIC X-RAY BACKGROUND EXPLORER (COBE)

A multidisciplinary team of physicists, instrumentation engineers, materials scientists, and computational scientists developed the differential microwave radiometer (DMR) and experimental techniques to observe the cosmic background radiation that is a remnant from the fiery beginning of our universe. They conducted ground-based radio-telescope observations, balloon-borne instrumentation, and satellite experiments. The most famous of these is COBE (the NASA Cosmic X-ray Background Explorer satellite), which has shown that the cosmic background radiation intensity has a wavelength dependence precisely that of a perfectly absorbing body indicating that it is the relic radiation from the Big Bang origin of the universe. Using COBE's differential microwave radiometer, George Smoot and his team of colleagues successfully mapped the early universe, discovering the seeds of present-day galaxies and clusters of galaxies. They also reveal information on the Big Bang and the origin of the universe. Smoot was the corecipient of the 2006 Nobel Prize in Physics for this work.

DISCOVERY OF DARK ENERGY

UCB scientists, led by Saul Perlmutter, conceived and developed the Supernova Cosmology Project, organizing the physicists, engineers, and mathematicians who produced the discovery of the accelerating expansion of the universe, the so-called Dark Energy of the universe. This entirely unanticipated discovery is comparable in

magnitude to the work honored by the 2006 Nobel Prize. Perlmutter and his colleagues have gone on to assemble the Supernova Acceleration Probe (SNAP) team, an international collaboration of more than 100 scientists as a Joint Dark Energy Mission supported by DOE and NASA. Management provided the support and charted the institutional arrangement to make this project a national priority for the astrophysics community. The project has a record of delivering on scientific and technical milestones, with outstanding community-wide reviews.

THE DISCOVERY OF THE PATHWAYS OF PHOTOSYNTHESIS

The University of California's Radiation Laboratory (now LBNL) began work on photosynthesis in the mid-1940s, utilizing advanced organic chemistry and radioactive labeling tools. UC developed the system of using carbon-14 as a tracer element, primarily applying this to the green alga *Chlorella*. The research team arrested the organism's growth at various stages and, by measuring the radioactive compounds present, was able to identify all the major reactions involved in the intermediate steps of photosynthesis. Melvin Calvin, leader of the research team, won the Nobel Prize in Chemistry in 1961 for this well-managed multidisciplinary effort.

EXTREME ULTRAVIOLET LITHOGRAPHY AND SEMATECH

SEMATECH, the consortium consisting of LBNL, Sandia National Laboratory (Livermore, CA), Lawrence Livermore National Laboratory, Intel, Motorola, Advanced Micro Devices, Micron Technology, Infineon Technologies, and IBM has been working to develop next-generation semiconductor lithography technology. This consortium developed a full-scale prototype machine that demonstrates all critical capabilities for making computer chips using extreme ultraviolet (EUV) light, beginning with a Cooperative Research and Development Agreement (CRADA) in 1997. LBNL's Center for X-Ray Optics (CXRO) is currently under a five-year, \$250 million industry-national laboratory effort and has achieved prototype fabrication of semiconductor devices with 30 nm design rule. Success is reflected in the fact that several of the sponsoring companies have now entered into proprietary agreements with CXRO to further commercial applications.

NEW GENERATION SYNCHROTRON SOURCES

LBNL scientists developed the first electron synchrotron (1940s) and invented and developed the first periodic magnet insertion devices (1970s) that led to the current generation of synchrotron radiation sources (1990s). The Advanced Light Source was completed on scope, schedule, and budget. With the development of superconducting bend magnets, the ALS was transformed from a soft x-ray facility to a universal synchrotron capable of high-resolution crystallography and tomographic biological imaging. The machine has produced the highest resolution structures of the RNA polymerase, the structure that transcribes the DNA sequence into RNA, and the ribosome, which translates the RNA sequence into a protein. In the case of the ribosome, the location of virtually every atom of the 300,000-atom machine was defined. Roger Kornberg, who was awarded the 2006 Nobel Prize in Chemistry for his work on the RNA polymerase structure, performed a good deal of his work at the facility.

SOYBEAN-CORN FREE-AIR CONCENTRATION ENRICHMENT (SOYFACE) PROJECT

Crops often respond very differently in the field to environmental perturbations and applications of chemicals than in greenhouses and other controlled environments. The ability to quantify these effects is critical

to predicting future global food supply and understanding how adaptation may be achieved. To gain experimental knowledge of how crops will respond to the simultaneous increase in carbon dioxide and surface ozone, it is therefore necessary to elevate these gases in the field under fully open-air conditions. The mission of the SoyFACE project was to engineer such an open-air facility and then operate it continuously over three full growth seasons to assess the impact of these changes in the atmosphere on the corn/soybean system, the largest single ecosystem type in the United States, incorporating the two most widely grown crops in the nation. The project, which coordinates the research of 30 PIs from seven nations at the one facility, completed its engineering development one year ahead of schedule and operated without failures over four complete growing seasons. This provided 36 replicated and wirelessly instrumented treatment plots over 80 acres of the South Farms adjacent to the UIUC campus.

JOINT GENOME INSTITUTE

The Joint Genome Institute was created in 1997 to unite expertise and resources in genome mapping, DNA sequencing, technology development, and information sciences pioneered at the three national DOE genome centers. JGI's staff of 240 was consolidated into the Production Genomics Facility near LBNL in 1999. JGI's 106 capillary sequencing machines are yielding, on average, 3.1 billion bases of sequence per month — establishing JGI as one of the leaders in sequence generation. With close to 400 genomes either in the works or sequenced, JGI leads all other centers worldwide. Beyond the generation of raw sequence, JGI also excels in the development of computational and bioinformatics tools that enable the assembly and annotation processes.

With the successful completion of the human genome, JGI reoriented its activities to generate genome sequence information from plants and microbes for DOE mission-driven research in the areas of bioenergy, carbon sequestration, and bioremediation applications. In the bioenergy feedstocks area, JGI has or is currently sequencing several plants:

- *Poplar*. Poplar (*Populus trichocarpa*), containing 4,500 protein-coding genes, is the most complex genome to be sequenced and assembled by a single public sequencing facility.
- *Switchgrass*. Another JGI sequencing target is switchgrass — a hardy perennial grass known for its rapid growth and a potential energy biomass crop.
- *Brachypodium*. The temperate wild grass species *Brachypodium distachyon* is a new model plant being studied by JGI for developing grasses into superior energy crops. *Brachypodium* is small in size and, thus, can be used as a functional model to develop superior energy crops.
- *Corn*. JGI is sequencing one of the chromosomes of a cultivar of corn (maize).

In the area of microbes and microbial communities JGI sequenced several microbes that enable the development of economical processes for converting biomass to fuel ethanol:

- *Clostridium thermocellum*, an anaerobic bacterium capable of directly converting cellulose from biomass into ethanol
- *Pichia stipitis*, a fungus that ferments xylose to ethanol, and degrades lignin and cellulose for the potential conversion of biomass to ethanol
- *Aspergillus niger*, a model for microbial fermentation and bioproduction of organic acids, enzymes, processing, and secretion of proteins
- *Pleurotus ostreatus*, a white-rot fungus and active lignin degrader commonly found inhabiting forest detritus and fallen trees

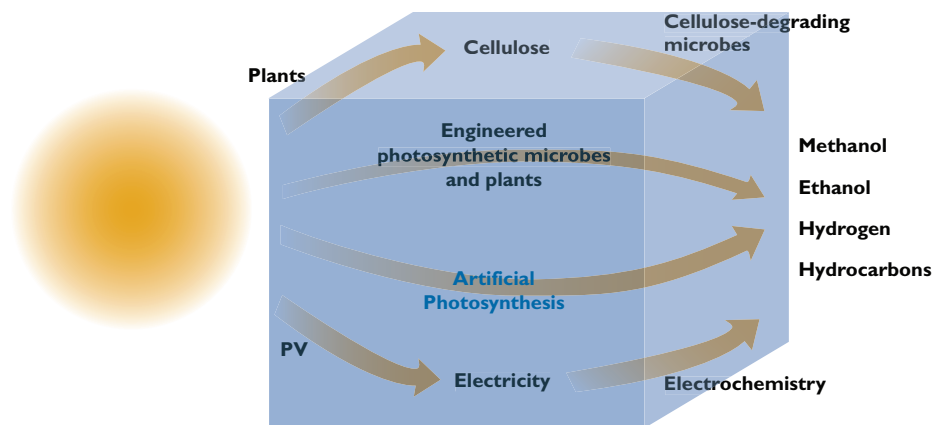
In addition to its efforts to sequence energy-related organisms, JGI has sequenced microorganisms responsible for bioremediation and carbon sequestration. These organisms include *Geobacter metallireducens*, *Desulfovibrio desulfuricans*, *Shewanella*, and *Burkholderia*. Finally, as part of its cross-cutting activities, JGI has pioneered an emerging discipline called metagenomics — isolating, sequencing, and characterizing DNA extracted directly from environmental samples — to obtain a profile of the microbial community residing in a particular environment. A recent metagenomics project, a collaboration with Caltech, Diversa (a California-based biotechnology company), and the government of Costa Rica, is devoted to isolating, sequencing, and harnessing the potential of enzymes produced by about 200 different species of microbes inhabiting termite hindguts — with a view toward optimizing the production of cellulosic ethanol.

HELIOS

The Helios project is a combined initiative of UCB and LBNL designed to enable and accelerate scientific breakthroughs and technological advances for the development of new carbon-neutral fuels. From a core group of UCB and LBNL scientists specializing in nanotechnology and synthetic biology, the group has now expanded to include colleagues from UC Davis, Caltech, MIT, the U.S. Department of Agriculture, and Stanford University.

Helios will include research programs that bring together biological and artificial nanoscale components for the creation of new materials. It will require leveraging the most recent advances in a variety of scientific fields, including catalysis, photochemistry, electrochemistry, biofuels, and photosynthesis. It will also require new advances in the emerging fields of synthetic biology and artificial nanostructures. As world leaders in many of these fields, UCB, LBNL, and their scientific partners have engaged their collective intellectual scientific breadth and world-class science facilities to tackle this problem. The new facility, described in “Buildings and Laboratory Facilities” section, will be designed to bring various disciplines under one roof to create a dynamic laboratory dedicated to carbon-neutral solutions to the energy problem, with an emphasis on transportation fuels. The figure below provides an overview of the pathways that will be considered in this initiative.

Helios Project Overview: Pathways



MICROBIALLY SOURCED ARTEMISININ

Malaria infects 300 million to 500 million people and causes as many as one million to two million deaths each year, primarily of children in Africa and Asia. More than half of the deaths occur among the poorest 20% of the world's population. One of the principal obstacles to addressing this global health threat is a lack of effective, affordable drugs. The chloroquine-based drugs that were used widely in the past have lost effectiveness because the Plasmodium parasite that causes malaria has become resistant to them. The faster-acting, more effective artemisinin-based drugs — as currently produced from plant sources — are too expensive for large-scale use in the countries where they are needed most.

Jay Keasling's laboratory at UCB and LBNL — working with Amyris Biotechnologies, a company that grew out of his laboratory, and the Institute for OneWorld Health, a non-profit pharmaceutical — received a \$42.6 million grant from the Bill & Melinda Gates Foundation to develop a microbial source for artemisinin and reduce the price by an order of magnitude. Keasling's laboratory has engineered E. coli and yeast to produce high levels of artemisinic acid, a precursor to artemisinin, and chemists at Amyris Biotechnologies have developed a simple chemical route to transform artemisinic acid to artemisinin. Currently, the teams at UCB and Amyris are optimizing the process for large-scale production of the drug. This scientifically risky project has rigid milestones that were met by the teams ahead of schedule and under projected costs. At its current pace, the drug is scheduled to be launched in late 2009 or early 2010, several years ahead of schedule.

CENTER FOR INFORMATION TECHNOLOGY RESEARCH IN THE INTEREST OF SOCIETY (CITRIS)

One of the major research initiatives at UCB is the Center for Information Technology Research in the Interest of Society. The goal of CITRIS is to develop the next generation of information and communications technologies, and to apply them to major economic and societal “grand challenges.” CITRIS has received \$100 million in funding from the State of California, matched by more than \$410 million in federally funded research and \$120 million in industrial and private support. Corporate partners include Intel, IBM, Microsoft, HP, British Telecom, Sun Microsystems, and Qualcomm.

Using technology developed at UC Berkeley and its “lablet” at UCB, Intel recently collaborated with BP to test the use of sensor networks to support preventive maintenance onboard an oil tanker in the North Sea. BP wanted to determine whether a sensor network could operate in a shipboard environment, where it would have to withstand temperature extremes, substantial vibration, and significant radio frequency noise in certain parts of the ship. A sensor network was installed onboard the ship and operated successfully for more than four months. During this trial deployment, the system gathered data reliably and recovered from errors when they occurred. BP is now exploring the use of sensor network technology in shipping, manufacturing, and refining operations.

SYNTHETIC BIOLOGY ENGINEERING RESEARCH CENTER (SYNBERC)

A new research center launched in summer 2006 at UCB will lay the groundwork for the emerging field of synthetic biology, which offers enormous potential for developing new pharmaceuticals, renewable energy sources, and industrial methods, and novel approaches to cleaning up environmental contaminants. Funded by a five-year, \$16-million grant from the National Science Foundation (NSF), the Synthetic Biology Engineering Research Center (SynBERC) is gathering pioneers in the field of synthetic biology from around the United States into a unique engineering center. The center's researchers hope to ignite the field of synthetic biology in the same way that the

developers of standardized integrated circuits in the 1960s ignited the field of semiconductor electronics. Matching funds from industry and the participating universities bring the total five-year commitment to \$20 million, with the NSF offering the possibility of a five-year extension of the grant. UCB's Jay Keasling directs the center. Center collaborators hail from MIT, Harvard University, UC San Francisco, and Prairie View A&M University in Texas. SynBERC engineers will make the designs for their biological parts and devices available to other engineers through an open-source registry of standard biological parts.

CODLING MOTH CONTROL PROGRAMS

Since 1993, UCB scientists have spearheaded research on the management of codling moths, the principal pest of apples, pears, and walnuts throughout most of the world. First initiated by UCB's Stephen Welter, a team of researchers developed pheromone mating disruption programs that reduce in-season organophosphate insecticide use by 75% in apple and pear orchards. This program has now become the standard program for roughly 50% of the acreage in the western United States (with greater than 90% in some regions).

Researchers are working to further reduce broad-spectrum pesticide use, expand the use of mating disruption in pome fruits and new cropping systems, and increase efficacy of biological control in orchards for secondary pests. In addition, the focus is on decreasing overall program costs, further reduction in labor inputs as labor availability continues to erode in U.S. agriculture, and increasing the reliance on bio-based management options to minimize non-target concerns for farm workers and the environment.

The project involves researchers from numerous disciplines at academic institutions in California, Oregon, and Washington, and has received funding from the USDA.

IV. STAFFING

UCB, LBNL, and UIUC have identified a team of highly qualified, creative, and experienced administrators, faculty, and senior staff to work with BP to develop the EBI agreement and provide support in the launch of the Institute. Each commits to the effort necessary to accomplish this endeavor, and the cost for their effort will be born by UCB, UIUC, and LBNL. Their resumé's are included in Appendix 7, p. 57.

UNIVERSITY LEADERSHIP

Beth Burnside

Vice Chancellor for Research, UCB
Professor, Department of Molecular and Cell Biology, UCB

Steve Chu

Director, LBNL
Professor, Department of Physics and Department of Molecular and Cell Biology, UCB
Nobel Laureate, Physics (1997)

Graham Fleming

Deputy Director, LBNL
Professor, Department of Chemistry, UCB

Paul Ludden

Dean, College of Natural Resources, UCB
Professor, Department of Plant and Microbial Biology

Charles F. Zukoski

Vice Chancellor for Research, UIUC
Professor, Department of Chemical and Biomolecular Engineering, UIUC

This group of senior administrators will work to develop the vision and strategic plan for the EBI. It is anticipated that the focus of their efforts will be to partner with BP to develop the governance and oversight structure for the Institute, and establish priorities and goals for initial directions and activities.

FACULTY SCIENTISTS

Jay Keasling

Professor of Chemical Engineering and Bioengineering, UCB
Division Director, Physical Biosciences Division, LBNL

Steve Long

Robert Emerson Professor, Department of Plant Biology, UIUC

Chris Somerville

Senior Scientist, Physical Biosciences Division, LBNL

These faculty leads will work with BP and university leadership to develop the scientific program and establish priorities for the near term. They will also assist in the development of the research program plan, research management plan, and scientific team, and they will plan the initial allocation of space and allocation of resources as determined by the Governance Board.

SENIOR STAFF

Ann Jeffrey

Assistant Vice Chancellor, Office of Research, UCB

Diane Leite

Deputy Director, California Institute for Quantitative Biological Research, UCB

Carol Mimura

Assistant Vice Chancellor, Intellectual Property & Industry Research Alliances, UCB

Leslie Millar

Director, Office of Technical Management, UIUC

These senior staff will work on negotiation of the EBI agreement with BP and on the set-up of the Institute.

Carol Mimura will oversee the development of the EBI agreement. She will work as the lead negotiator with BP and will be responsible for coordinating with subcontractors, with the UC Office of the President, with internal and external counsel, and with other stakeholders. She will chaperone the process, and serve as the liaison between UCB and BP on all issues related to the development of the final master agreement. Leslie Millar will work with Dr. Mimura to ensure a streamlined interface with UIUC.

Ann Jeffrey and Diane Leite will work with university leadership and the lead scientists to assist with the set-up of the Institute. Ms. Jeffrey will assist in the establishment of the EBI within the UCB infrastructure, and will act as liaison to the UIUC research operations and to UCB support offices. Ms. Leite will advise on the development of an operational infrastructure for the Institute, on the development and implementation strategies to integrate scientific interests into collaborative programs, and on the structuring of research concepts into interlocking components of a coherent program among the participating institutions.

V. COST

As requested in the RFP, we here provide approximate costs for the development of the operating agreement and content definition, and discuss fixed overhead charges for the EBI. We also provide an overview cost-analysis of some of the key components of the programs that we are proposing.

DEVELOPMENT OF THE OPERATING AGREEMENT

We anticipate that costs to develop the operating agreement and content definition will be minimal. Because we are proposing to use existing university infrastructure for contracts and grants management, the EBI agreement will be negotiated and finalized through the UCB Industry Alliances Office (IAO) in consultation with the UC Office of General Counsel (OGC) and the contract offices at LBNL and UIUC. There are no direct charges foreseen related to development of the agreement or contract negotiation that UCB will charge to BP.

In order to get the research program moving as quickly as possible, there is functional program definition work that should occur in partnership with BP prior to the program start date. To expedite this process, we propose bringing on key members of the management team and senior operations staff for the open research side of the Institute prior to the start of the research program to assist with the program's design and set-up. We anticipate that these positions would include the director, the associate director, the deputy director, the chief technical officer, the administrative director, and several support staff. In addition, a modest supplies and travel budget would be needed to support their organizational efforts. Finally, in order to accommodate an immediate start for the director, early funding for equipment and renovation as part of a standard faculty start-up package is requested.

EBI PROGRAM COSTS

The EBI, as envisioned in this proposal, provides the Governance Board (GB) with significant flexibility in determining the allocation of research funding. At the same time, there are fixed costs related to the programs that we have outlined. These fall into three broad categories: university indirect costs, direct costs related to management and leadership of the Institute and its research programs, and costs related to the proprietary work component to be executed as part of the EBI budget, such as rent paid by BP for space within the Institute for BPI applied research.

Indirect costs. University policy requires extramural sponsors to pay the full costs of sponsored research, both direct and indirect. The UCB on-campus indirect cost rate is currently 52%. The campus is currently negotiating a new rate with the Department of Health and Human Services (DHHS), but it is unlikely that the rate will increase more than a few points. Indirect costs are assessed against almost all direct costs, with a few exclusions. Exclusions most relevant to the proposed work funded by BP are subcontracts (beyond an initial \$25,000) and capital equipment. The indirect cost assessment reimburses the campus for such things as operations and maintenance of plant, central administrative services, and basic EH&S services. A portion of the indirect cost assessment (equivalent to approximately 75% of direct expenditures) will be returned to the Institute to fund research administration staff and expenses. The UIUC indirect cost rate is roughly the same as the UCB rate (53%) and will be charged on the same basis as the UCB rate against relevant direct costs incurred at UIUC. The intermixing of UCB and LBNL participants makes the assessment of the LBNL rate less obvious, but we anticipate that overhead costs at Berkeley for both UCB and LBNL components will be essentially the same.

Management and Leadership of the Institute and Its Research Programs. A cost analysis of the management model and research program laboratory structure that we envision is outlined in the tables that follow.

Proposed program costs related to the open research program fall into two general categories —management of the Institute overall, and leadership within the research laboratory structure. An overview of each category follows. Each includes both direct costs, mostly salaries and benefits, and associated indirect costs. These expenses are expected to be incurred across all partner institutions. However, for simplicity, the UCB indirect cost rate is used for illustration. Both tables assume an annual cost-of-living adjustment of 3.5%. A benefits rate of 20% is used for all positions except the support staff, which is calculated at 25%.

MANAGEMENT AND LEADERSHIP COSTS	Year 1	Year 2	Year 3	Year 4
Salaries & Benefits				
Director & Deputy Director (2 partial FTE)	630,000	650,000	670,000	700,000
EBI Program Directors (3 FTE — 6 @ 50% each)	961,200	994,800	1,029,600	1,065,600
Project Manager (UCB) & Deputy (UIUC) (1.5 FTE)	180,000	186,300	192,800	199,500
Operations Director (UCB) & Deputy (UIUC) (1.5 FTE)	225,000	232,900	241,100	249,500
Facilities, Health & Safety Director (UCB) & Deputy (UIUC) (1.5 FTE)	180,000	186,300	192,800	199,500
Technology Transfer Director (1 FTE)	192,000	198,700	205,700	212,900
Communications, Education & Outreach Director (1 FTE)	108,000	111,800	115,700	119,700
Support Staff (8 FTE)	600,000	621,000	642,700	665,200
Subtotal Salaries & Benefits	3,076,200	3,181,800	3,290,400	3,411,900
Non-salary Expense (supplies, travel, etc.)	300,000	310,500	321,400	332,600
Education, Outreach & Communications Program	200,000	350,000	500,000	517,500
Total Direct Costs	3,576,200	3,842,300	4,111,800	4,262,000
Indirect Cost @ 52% (UCB rate)	1,859,600	1,998,000	2,138,100	2,216,200
TOTAL MANAGEMENT AND LEADERSHIP COSTS	\$ 5,435,800	\$ 5,840,300	\$ 6,249,900	\$ 6,478,200

A detailed description of the roles and responsibilities of the management and senior operations staff positions listed in the “Management and Leadership Costs” table is included in the section “Director and Senior Staff of the Institute.” We are proposing an aggressive recruitment schedule that fully staffs the leadership and senior positions early in the first year. However, the Education, Outreach, and Communications Program is anticipated to ramp up over the first two to three years of the EBI.

PROPOSED RESEARCH PROGRAM COSTS	Year 1	Year 2	Year 3	Year 4
Salaries & Benefits				
(EBI Laboratories — Lead Investigators & Managers)				
New Faculty Hires — 5 hires/year starting Year 2 (50% salary from EBI)		450,000	931,500	964,100
Laboratory Lead Investigators Summer Salary — 25 @ 3 months	1,500,000	1,552,500	1,606,800	1,663,000
Discovery & Development Center Managers (5 FTE)	540,000	558,900	578,500	598,700
Subtotal Research Program Management	2,040,000	2,561,400	3,116,800	3,225,800
BP Fellows Program				
(Five fellows in Year 1, increasing to 10 in Year 4)				
Salaries & Benefits	390,000	403,700	417,800	864,800
Research Support	500,000	517,500	535,600	1,108,700
Subtotal BP Fellows Program	890,000	921,200	953,400	1,973,500
Faculty Start-up Packages for New Hires — renovation costs	3,000,000	1,000,000	1,000,000	
Indirect Cost @ 52% (UCB rate)	3,083,600	2,331,000	2,636,500	2,703,600
Faculty Start-up Packages for New Hires — equipment		5,000,000	5,000,000	
PROPOSED RESEARCH PROGRAM COSTS	\$ 9,013,600	\$ 11,813,600	\$ 12,706,700	\$ 7,902,900

The “Proposed Research Program Costs” table above reflects the research program and laboratory structure described in the “Research Program” section. Salary costs for the program directors are reflected in the “Management and Leadership Costs” table, but summer salary support for the lead investigators of the approximately 25 laboratories, partial salary support for new faculty recruited through the partner institutions for the EBI, and salary support for the five managers of the Discovery and Development facilities are reflected in the table above. Also included are new faculty start-up package costs. Finally, costs are projected for the BP Fellows Program, described in the section “Staffing of Principal Investigators, Graduate Students, and Postdoctoral Fellows”. Costs in Years 2 and 3 are higher than in Year 4 due to estimated start-up package costs for new faculty hires. The estimate for Year 4 reflects steady-state costs, and we estimate that these will increase by the cost-of-living factor in Years 5 through 10.

EBI — SUMMARY OF PROPOSED COSTS	Year 1	Year 2	Year 3	Year 4
Management and Leadership	5,435,800	5,840,300	6,249,900	6,478,200
Proposed Research Program Costs	9,013,600	11,813,600	12,706,700	7,902,900
TOTAL PROPOSED COSTS	\$ 14,449,400	\$ 17,653,900	\$ 18,956,600	\$ 14,381,100

We have proposed these project costs (summarized above) with the thought in mind of being the highest quality provider, not the least cost provider. At the same time, we have strong experience in cost management and will utilize only the funds needed to provide an effective infrastructure for the Institute as ultimately defined by BP and the partner institutions in the development of the scientific and management programs of the EBI. The summary above provides approximate fixed costs of the structure articulated in this proposal. However, it is our expectation that final definition of program and structure may change significantly as joint goals and approaches are clarified with BP.

Costs Related to the Proprietary Research Program. There may be fixed costs related to proprietary work done under the EBI. Given the proposed management structure of the Institute, fixed operating needs would be determined by the BP associate director in consultation with the GB. One component of these fixed costs will be rental of any space designated for proprietary applied research within the EBI at either UCB or UIUC, and thus will reflect space needs of the proprietary component. Rental rates will be based on market rates and negotiated separately.

VI. INCENTIVE ELEMENTS

Our bid for the EBI includes several incentive elements. These are outlined below. While some of these incentives are dependent on the award of the EBI to UCB, LBNL, and UIUC, none of them carries any additional restrictions or obligations.

State of California Contribution. The State of California has committed \$40 million toward a dedicated facility for the EBI. (See Governor Schwarzenegger’s letter of support following this section.) The facility is planned to be at least 50,000 assignable square feet and will house wet laboratory/office space that is specifically designed to enable cross-disciplinary assignments and foster interaction and collaboration. To date, the funding sources that have been identified for this facility include \$15 million in private donations, \$30 million in California Lease Revenue bonds, and \$30 million in University of California bonds. The additional \$40 million from the State will enable us to build a larger facility with a Leadership in Energy and Environmental Design (LEED) rating of Platinum.

New Faculty FTE. To demonstrate our commitment to research and teaching in the area of energy biosciences, UCB, LBNL, and UIUC will recruit for 10 new faculty positions for key areas within the EBI. Seven of these new positions will be UCB/LBNL faculty, and three will be UIUC faculty. We envision that these positions will be jointly funded with the EBI, and that these faculty members will be instrumental in setting new directions for teaching and research in this new field of the biosciences.

Institutional Investment and Commitment — LBNL. LBNL has committed \$5 million in seed project-funding for a solar-to-fuels effort (Helios). These research projects represent LBNL’s investment in a broad-based strategy for solar fuel generation. (See the “Qualifications (Mission-Driven Initiatives)” section for a full description of the Helios effort.)

State Investment — Illinois. The State of Illinois has provided the Institute of Genomic Biology building and facilities to UIUC at a cost of \$75 million. The integrated office, laboratory, and support space provided to the EBI at UIUC will occupy about 25% of the building, representing a State contribution of approximately \$20 million. The State will also provide through UIUC an initial 340 acres of farmland, currently valued at \$4 million.

Access to Services and Amenities. BP investigators on the proprietary side of the Institute will be given affiliate status, which will grant them access to computers, libraries, research facilities, and other resources of the three campuses such as dining, parking, and recreational activities. BP investigators will also have access to all UCB, LBNL, and UIUC analytical facilities noted earlier in the proposal on a fee-for-service basis. It is anticipated that all members of the EBI will interact seamlessly as part of the campus communities. We expect to develop opportunities for BP scientists to mentor undergraduate students, graduate students, and postdoctoral fellows; to participate in the design and development of courses and seminar series; and to audit undergraduate and graduate courses.

Enabling Technology for Collaborative Research — UCB. State-of-the-art, “telepresence” meeting rooms will be constructed at UCB and UIUC to support meetings between researchers at the two locations. These meeting rooms provide nearly the same quality of interaction as in-person meetings. Cisco’s

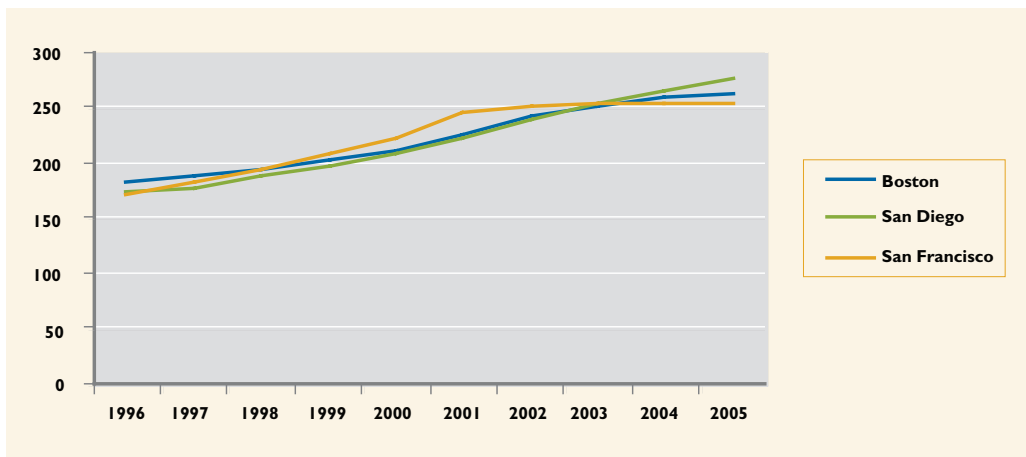
TelePresence product will be the centerpiece of these facilities, using life-size, ultra-high definition video displays and spatially discrete audio to create a virtual meeting room encompassing both locations. This full-immersion environment provides a near real-time experience of a live, face-to-face meeting around a “virtual” meeting table.

Guest Housing. LBNL is building an on-site Guest House to provide convenient, affordable housing for non-local guests visiting LBNL and UCB science facilities. The facility will include 61 guest rooms and 70 to 80 beds in six different room types. The project is currently in concept design, with construction slated to begin in fall 2007 and completion set for early winter 2009. At UIUC, on-campus guestrooms are centrally located at the Illini Union, which has 72 rooms and two VIP suites. Each room includes high-speed Internet access, continental breakfast, free local calls, air conditioning, cable TV, voice mail and fax services, laundry and dry cleaning, and free parking. For guests with special needs, smoke-free and barrier-free rooms are available. A commercial-suite hotel is also located within a mile of campus.

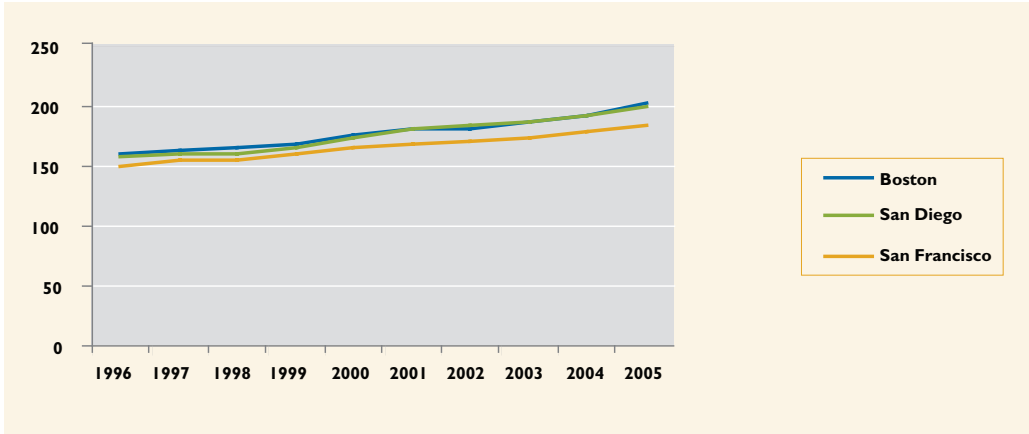
Cost of Living. The San Francisco Bay Area offers a lower cost of living than San Diego, Boston, or London. Mercer Human Resources Consulting, in its Worldwide Cost of Living Survey for 2006, ranks London as #5 and San Francisco as #34 (less expensive). A chart showing Consumer Price Index (CPI) comparison data for Boston, San Diego, and San Francisco is provided below. It shows that, while all three metropolitan areas have similar costs, San Francisco’s are the lowest across all categories.

Matching Grant Opportunities. The University of California Discovery Grants Program provides an opportunity to leverage BP funds. UC Discovery Grants invest in the success of the technology-driven California economy by providing matching funds for industry-sponsored cooperative research. BP can partner with UC researchers to identify problems of common interest, develop research proposals with objectives, milestones, and timelines, and submit them to the Discovery Grant Program. Approved grants are matched dollar-for-dollar and provide one to four years of support for basic through proof-of-concept research projects. Appropriate projects described in Research Project Descriptions (RPDs) would be eligible for application to this program.

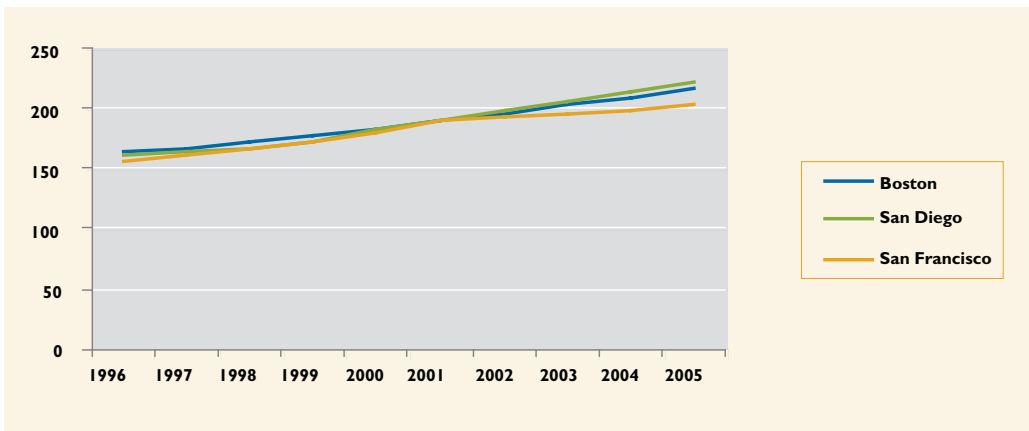
CPI Cost of Shelter: Boston, San Diego, and San Francisco Metro Areas



CPI All Items Except Shelter: Boston, San Diego, and San Francisco Metro Areas



CPI All Items Including Shelter: Boston, San Diego, and San Francisco Metro Areas





GOVERNOR ARNOLD SCHWARZENEGGER

November 20, 2006

The Right Honorable Lord Browne of Madingley
Group Chief Executive
BP, PLC
1 St. James's Square
London, SW1Y4PD
United Kingdom

Dear Lord Browne,

I am writing to express my strong support for the proposals by the University of California, Berkeley and the University of California, San Diego for BP's new Energy Biosciences Institute (EBI).

As you know from our discussions, I am enthusiastic about BP's long-term technology strategy and its focus on energy biosciences and renewable fuels. It is a great honor that two California research universities have been selected to compete for this important and transformational research initiative. California is the ideal setting for this venture given its rich culture of innovation and discovery, outstanding research tools and unparalleled intellectual capital. There is no comparable environment that provides the same level of expertise, breadth of capabilities and access to scientific resources.

As we have discussed, it is a top priority of my administration to advance renewable energy technology. California has already made great strides in recognizing the dangers of global warming and in addressing our energy challenges and opportunities. In the last year alone we have made remarkable progress, including signing into law the Global Warming Solutions Act, the first statewide effort to cap greenhouse gas emissions across all sectors of California's economy, launching the Million Solar Roofs Initiatives that will bring 3,000 megawatts of clean energy online by 2017, requiring the State to acquire 20 percent of electricity from renewable sources by 2010 and issuing a detailed BioEnergy Action Plan, which targets the production and use of biofuels and biomass for electricity. The BP initiative would be another major step forward for California in this area and would receive the highest attention from my administration to help ensure its success.



The Right Honorable Lord Browne of Madingley
November 20, 2006
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All of the institutions invited to compete for the EBI are world-class. However, I believe that with our track record of innovation and entrepreneurial spirit, California and the EBI are a perfect match. With a workforce and business climate dedicated to discovery and research advances ranging from the work of pioneering physicist E.O. Lawrence, to the birth of Silicon Valley, to our modern-day biotech clusters including emerging stem cell research centers, California stands as a ready partner to BP.

California and my administration are prepared to work with you to make the EBI a reality and ensure its success. To supplement the University of California's proposals, I pledge \$40 million to support construction of appropriate facilities for the EBI if one of the UC campuses is selected by BP. Thank you again for your consideration and for BP's commitment to new and cleaner energy sources.

Sincerely,

A handwritten signature in black ink, appearing to read "Arnold Schwarzenegger". The signature is stylized and cursive, with a long horizontal stroke extending to the right.

Arnold Schwarzenegger