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The DOE Bioenergy Research Centers (BRCs)

Briefing for Biomass R&D Technical Advisory Committee

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Basic Rationale for DOE Bioenergy Research Centers

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- Cost-effective production of cellulosic biofuels will require transformational breakthroughs in basic science
- The scientific problem is highly challenging, but very well defined
- Genomics-based systems biology provides powerful new tools for re-engineering plants, microbes, and enzymes at the system, cellular, and molecular levels—to achieve major efficiencies and cost reductions in biomass-to-biofuels production
- Objective: basic scientific research designed "to develop usable knowledge that will . . . ultimately lead to technologies deployable in the nation's energy economy"

A Field Ripe for Breakthroughs

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- In contrast to agricultural crops (e.g., corn yields X 7 since 1930s), little work has been done to hybridize and optimize bioenergy crops (e.g., switchgrass, miscanthus)
- Current bioprocessing relies on a handful of enzymes, a tiny subset of the cellulases available in the microbial world; also, new and reengineered microbes could greatly improve deconstruction, fuel synthesis
- Very little is understood about the nanoscale mechanisms of conversion—the highly complex structure of cell walls where lignocellulose (plant fiber) is embedded, and the actual operation of enzymes
- New tools give us major capabilities to understand and transform these processes

A New Generation of Technologies to Accelerate Discovery

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- **Genomic Sequencing** (DOE Joint Genome Institute: 3 billion base pairs per month)
  - Provides unprecedented capabilities for understanding and modifying organisms (both plants and microbes) – JGI recently sequenced poplar, working on switchgrass, multiple microbes
  - **Foundational** for BRC science
- **High-Throughput Screening/Assays**
  - Key to accelerating pace of discovery – using current technologies and developing new ones
- **Bioprospecting/Metagenomics**
  - Scouring Nature for new, more effective cellulases
- **Directed Evolution (utilizing a new generation of sequencing technologies)**
  - Letting Nature to do our work for us—controlled natural selection to accelerate development of optimized microbes
  - Aimed at developing microbes more effective at degrading lignocellulose as well as fuel-synthesis microbes that resist pretreatment toxins, high titer
- **Synthetic Biology**
  - Redesigning microbes to produce molecules more like petroleum-based fuels
  - Redesigning microbes for Consolidated Bioprocessing (CBP)—one-microbe or microbe commmunity approach to deconstruction and fuel synthesis)
- **Advanced Imaging (NMR, High-Intensity Light Sources)**
  - Taking advantage of new capabilities of observing at nanoscale in ultrafast time intervals
- **High-End Computational Modeling**

Making Cellulosic Ethanol

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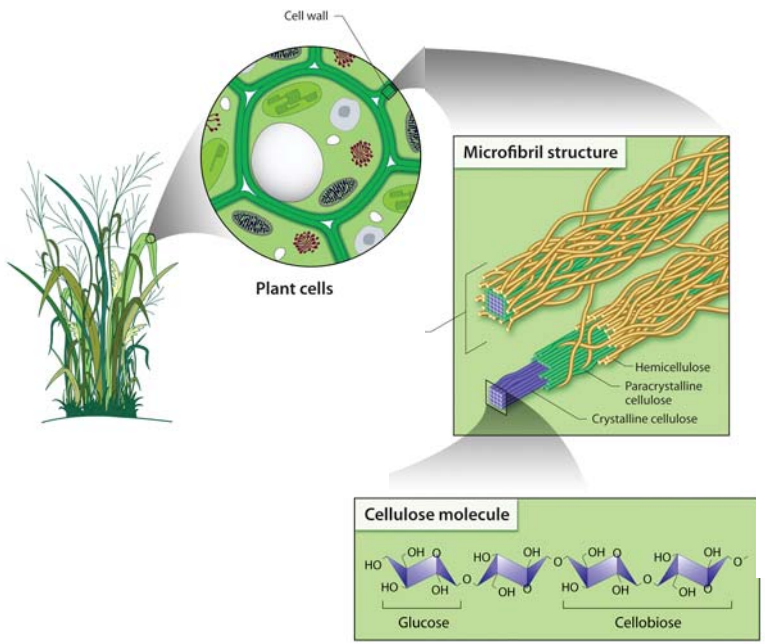
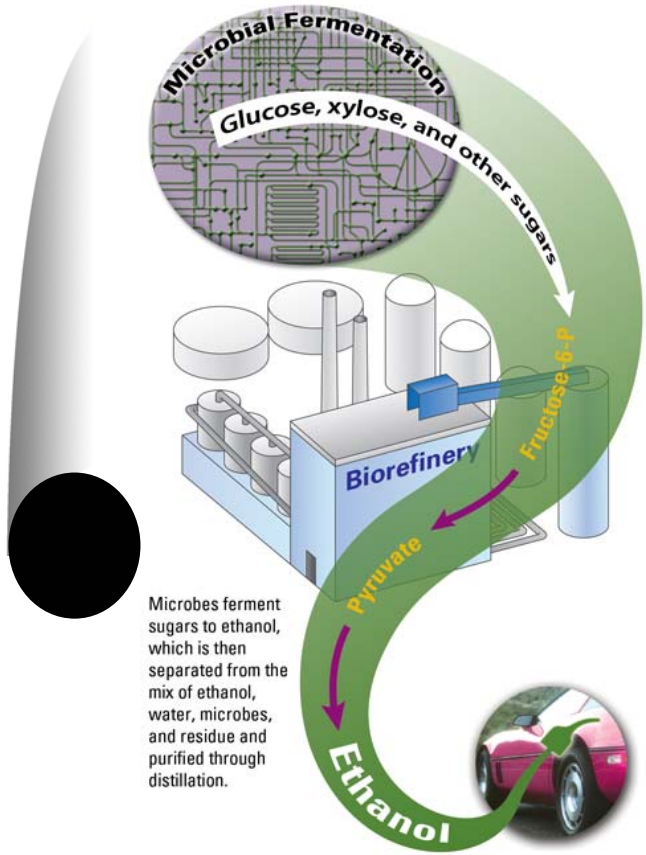
Basic Transformation

Lignocellulose → Sugars → Ethanol





A Clear Roadmap with 5 Major Focus Areas

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- Feedstocks
- Deconstruction (overcoming "recalcitrance")
- Fuel Synthesis
- Enabling Technologies to Accelerate Research
- Tech Transfer, Commercialization

Bioenergy Research Centers Overview

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- Funding: **$405 million** to be provided **over five years** to establish and operate **three** new **Bioenergy Research Centers**—part of DOE Office of Science Genomics: GTL program (systems biology for DOE missions in energy, environmental clean-up, and carbon cycling and biosequestration)
- Goals: **transformational discoveries** in basic science to make production of **cellulosic ethanol** and other biofuels cost-effective and economically viable
- Method: advanced systems biology research on **plants** and **microbes** – builds on DOE Human Genome Project legacy
  - Developing and modifying dedicated bioenergy feedstocks
  - Overcoming "recalcitrance" of lignocellulose – cost-effective deconstruction
  - Microbial synthesis of fuels – ethanol and beyond
- Innovative multidisciplinary approach: **no construction, rapid start-up** – utilizing **latest biotechnology advances** plus **world-class instruments in DOE complex** (Joint Genome Institute, high-intensity light sources, etc.)
- **Open competition**: universities, national labs, nonprofits, private firms, and **partnerships** competed – selection based on peer review evaluation by 30+-scientist international panel.
- Three Centers, all multi-institutional partnerships, are now up and running, will receive a total of $35 M each in FY07-08
- Geographically dispersed, with diversified and complementary scientific agendas

Bioenergy Science Center (BESC)

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Lead Institution: Oak Ridge National Laboratory
Headquarters: Oak Ridge, TN

Partners:

- Georgia Institute of Technology
- National Renewable Energy Laboratory (NREL)
- University of Georgia
- University of Tennessee
- Dartmouth College
- ArborGen
- Verenium Corporation
- Mascoma Corporation
- The Samuel Roberts Noble Foundation
- Individual researchers from the University of California Riverside; Brookhaven National Laboratory; Cornell University; Virginia Tech; University of Minnesota; and Washington State University

Great Lakes Bioenergy Research Center (GLBRC)

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Lead Institution: University of Wisconsin-Madison, in partnership with Michigan State University

Headquarters: Madison, WI

Additional Partners:

- University of Florida
- Iowa State University
- Illinois State University
- Lucigen Corporation
- Oak Ridge National Laboratory
- Pacific Northwest National Laboratory (PNNL)

Joint BioEnergy Institute (JBEI)

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Lead Institution: Lawrence Berkeley National Laboratory

Location: Emeryville, CA

Partners:

- Lawrence Berkeley National Laboratory
- Sandia National Laboratories
- Lawrence Livermore National Laboratory
- University of California at Berkeley
- University of California at Davis
- Carnegie Institution Department of Plant Biology

BRC Timeline

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- August 1, 2006 – DOE issues Funding Opportunity Announcement for 2 BRCs
- February 1, 2007 – Proposals Due
- February – June – Merit Review by international panel of 30+ experts
- June 26 – Secretary announces selection of 3 BRCs
- July – September – DOE negotiations on terms and conditions of awards
- End of September – Agreements concluded; initial funding provided for BRCs of FY2007 ~$10 million each
  - Agreements require BRCs to have clear, well-structured management plans and procedures; effective quality control/performance appraisal for research; and clear scientific milestones/deliverables to help focus and accelerate research programs
- DOE Technical and Management Review, Bethesda, MD, November 27-29
  - Early review designed to help BRCs get management plans and procedures in place as expeditiously as possible and to assist with outside advice
  - Evaluated BRC management plans and procedures
  - In-depth briefing on BRC science programs, with detailing of science milestones
- All three BRCs are currently up and running and conducting research in existing facilities
  - BESC moving into state-financed Joint Institute for Biological Sciences building
  - JBEI has leased space in Emeryville, CA; will be moving in in April-May window
  - GLBRC operating in new building on UWM campus and will have yet another new state-financed $100 million building in 3 years
- DOE review of BRCs planned for end of year 1

BioEnergy Science Center (BESC)

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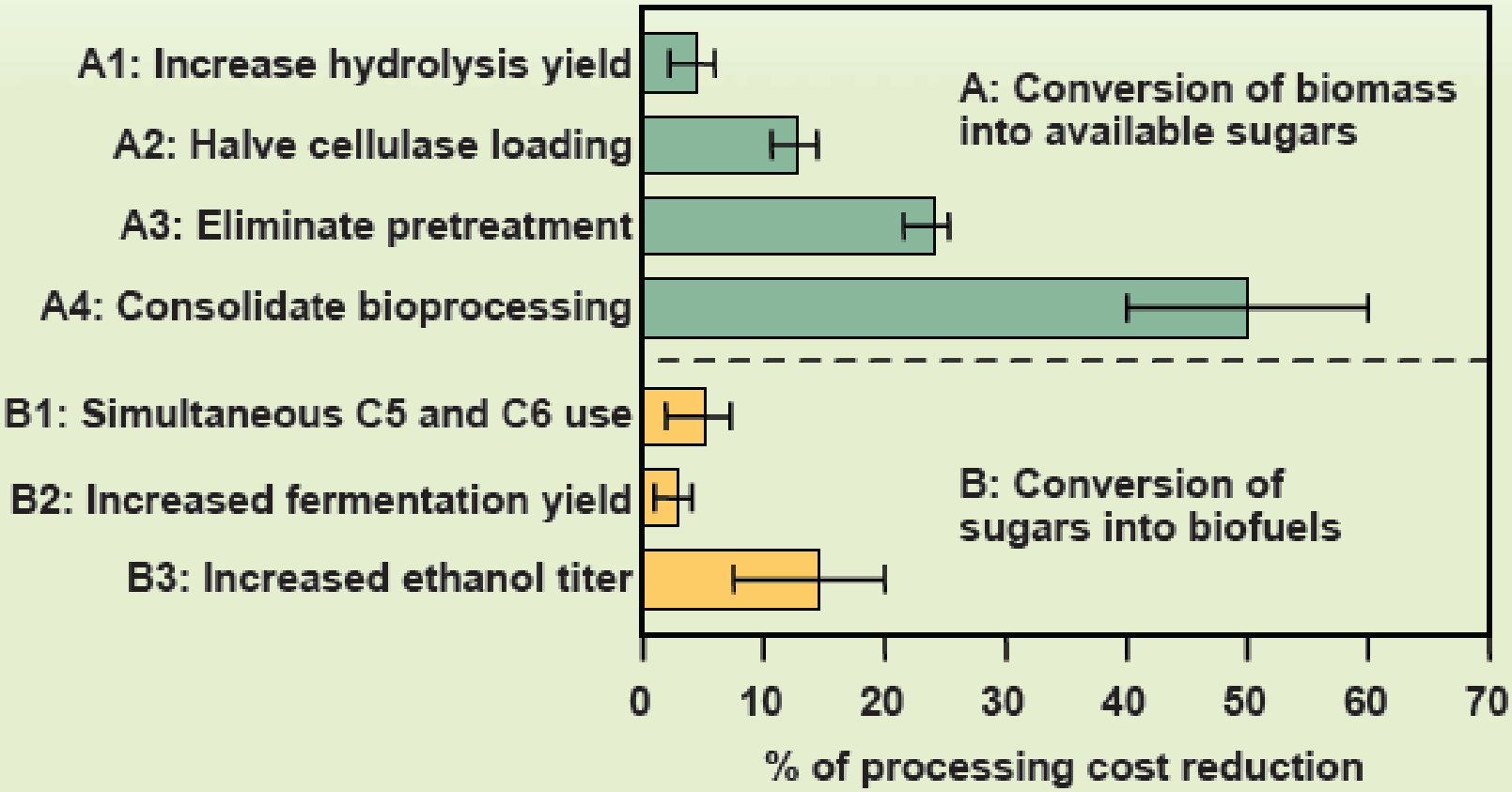
- Strong central **strategic focus** on overcoming "recalcitrance" (resistance of plant fiber, or lignocellulose, to breakdown into sugars) as major route to cost savings and cost-effective biofuels production
- Goal of "Consolidated Bioprocessing" (CBP) – one-microbe or microbial community approach going from plants to fuel
- Working directly on energy crops – switchgrass and poplar
- Developing new high-throughput technologies to screen thousands of genetic variants of switchgrass and poplar for amenability to deconstruction—a "brute force" approach
- Bioprospecting in Yellowstone National Park for cellulases that operate more efficiently at very high temperatures
- Synthetic biology to make *Clostridium thermocellum* (CBP microbe) more efficient at fermenting and to re-engineer the cellulosome
- Strongly committed to achieving cost-saving, commercializable breakthroughs in five years
- Will eventually have the opportunity to test discoveries in a demonstration biorefinery being constructed by the state of Tennessee 40 miles from BESC

Comparative impacts of R&D on biomass processing cost



Without overcoming biomass recalcitrance (A), cellulosic biofuels will be more expensive than corn biofuels. Improved sugar conversion (B) is not enough.

Ref: Lynd, L.R., M.S. Laser, D. Bransby, B.E. Dale, B. Davison, R. Hamilton, M. Himmel, M. Keller, J.D. McMillan, J. Sheehan, C.E. Wyman, 2007. "Energy Biotechnology: Targeting a Revolution" Nature Biotechnology (in press)

BESC BioEnergy Science Center

Joint BioEnergy Institute (JBEI)

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- Strong **basic science-oriented** approach, looking for fundamental *transformational*, game-changing breakthroughs in basic science
- Focusing on model crops of *Arabidopsis* and rice (and on switchgrass) – with idea that basic science breakthroughs can be achieved more rapidly on model crops and then transferred to energy crops
- Innovative approach to lignin – rather that treat lignin as a wall to be broken through, change the monomer composition of lignin to make it more cleavable and its byproducts less toxic to microbes used in fuel synthesis
- Especially innovative on the microbial side – using synthetic biology, looking beyond ethanol to synthesis of butanol, isopentanol, hexadecane, geranyl decanoate (more like gasoline)
- All researchers will work together in a newly leased lab building near Berkeley
- Fostering strong connections to larger S.F. Bay Area Biotech Community, which is becoming hub of bioenergy technology and venture investment

Great Lakes Bioenergy Research Center (GLBRC)

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- Reflecting agronomic orientation of the two universities, will focus on a wide range of plants, including both “model” plants and potential bioenergy crops – also in some ways the most diverse research agenda
- Alternative approach to plants – in addition to working to overcome “recalcitrance” of lignocellulose, GLBRC will be re-engineering plants to produce more starches and oils, which are more easily processed into fuels
- Alternative approaches to fuels:
  - Re-engineer E.coli to produce “green gasoline”
  - Develop microbial biorefineries that can use sunlight and plant biomass to generate hydrogen, electricity, or high-energy chemicals
- Includes major “thrust area” on **sustainability** of biofuels production, comprehensively studying the environmental and socioeconomic dimensions of moving to a biofuels economy (not requested in FOA, but widely praised by peer reviewers and important for moving toward President’s “20 in 10” goal)

For More on BRCs and BRC Science

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http://www.science.doe.gov/ober/berac/11-07info.html

http://genomicsgtl.energy.gov/centers/