Presentation to the Hydrogen and Fuel Cell Technical Advisory Committee
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Biological Hydrogen Production: Fundamental Research on Systems Biology

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Biological and Environmental Research Mission

• To understand complex biological, climatic, and environmental systems across spatial and temporal scales.

• BER provides the foundational science to:
  – Support the development of biofuels as major, secure, and sustainable national energy resources
  – Understand potential effects of greenhouse gas emissions on Earth’s climate and biosphere and the implications of these emissions for our energy future
  – Predict the fate and transport of contaminants in the subsurface environment at DOE sites
  – Develop new tools to explore the interface of biological & physical sciences
# Biological and Environmental Research

## Budget

<table>
<thead>
<tr>
<th>Appropriations</th>
<th>FY09</th>
<th>FY10</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Research</strong></td>
<td></td>
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<tr>
<td>Biological Systems</td>
<td>$173M</td>
<td>$166M</td>
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<tr>
<td>Bioenergy Research Centers</td>
<td>$75M</td>
<td>$75M</td>
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<tr>
<td>Climate Change Research</td>
<td>$132M</td>
<td>$134M</td>
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<tr>
<td>Subsurface Biogeochemical Research</td>
<td>$49M</td>
<td>$50M</td>
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<tr>
<td><strong>Total</strong></td>
<td>$429M</td>
<td>$425M</td>
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<tr>
<td><strong>Facilities:</strong></td>
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<td><strong>Scientific User Facility Operations</strong></td>
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<tr>
<td>Joint Genome Institute (JGI)</td>
<td>$65M</td>
<td>$69M</td>
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<tr>
<td>Atmospheric Radiation Measurement (ARM)</td>
<td>$40M</td>
<td>$42M</td>
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<tr>
<td>Environmental Molecular Science Laboratory (EMSL)</td>
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<td>$52M</td>
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<td><strong>Total</strong></td>
<td>$154M</td>
<td>$163M</td>
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<tr>
<td><strong>Other</strong></td>
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<tr>
<td>(e.g., Small Business Innovation Research)</td>
<td>$17M</td>
<td>$16M</td>
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<tr>
<td><strong>Total BER</strong></td>
<td>$600M</td>
<td>$604M</td>
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## Biological and Environmental Research Divisions

### Biological Systems Science Division

- Genomic Sciences Program
- Bioenergy Research Centers
- DOE Joint Genome Institute
- Low Dose Radiation
- Radiochemistry, Imaging, and Instrumentation
- Structural Biology

### Climate and Environmental Sciences Division

- Climate Change Research
- ARM Climate Research Facility
- Subsurface Biogeochemical Research
- Environmental Molecular Sciences Laboratory
Genomic Sciences Program

DOE Genomic Science Program
A Mission-Inspired Fundamental Research Approach

Technologies and Methods for Systems Biology
- Microbe genomics, plant genomics, metagenomics
- Analysis of global changes in gene expression and metabolite profiles
- Molecular imaging
- Structure determinations
- Modeling and simulation
- Prediction and design
- Synthetic biology

Fundamental Research Needs
- Gain a predictive understanding of how cells work in communities, tissues, plants, and, ultimately, global ecosystems
- Explore the functioning and regulation of pathways and dynamic networks in cells
- Understand how proteins function individually and in interactions with other cellular components
- The genome determines dynamic biological structure and function at all scales, from genes to ecosystems.

Mission Grand Challenges for Biology

Energy
- Tools and concepts for designing and engineering bioenergy plant and microbial systems, including the mechanistic bases.

Carbon Cycle
- Tools and concepts to determine the carbon-cycling and sequestration processes of ocean and terrestrial ecosystems.

Environmental Remediation
- Microbial and plant modeling and experiments to predict and control contaminant fate and transport.

Payoffs for the Nation
Technology Endpoints
Sustainable and Viable Biofuel Technologies
Earth System Modeling and Biosequestration Strategies
Improved Strategies for Environmental Remediation and Long-Term Stewardship
DOE Scientific User Facility
DOE Joint Genome Institute

• Focus: Genomes and metagenomes of microbes, microbial communities, and plants vital to DOE missions
  – Provide state-of-the-art capabilities for sequencing and analysis
  – Maintain expert staff in a range of computing and biological research disciplines
  – Host workshops and annotation jamborees

Sequencing more than 1 tera base pairs of DNA per year or 333 human genome equivalents!
DOE Joint Genome Institute: Biohydrogen Relevant Sequencing

JGI has provided sequencing of whole genomes, expressed sequence tagged (EST) libraries, and metagenomes of:

- Hydrogen-producing bacteria
- Hydrogen-producing algae
- Intact microbial communities
DOE Scientific User Facility
Environmental Molecular Sciences Laboratory

- EMSL science themes:
  - Biological interactions and dynamics
  - Geochemistry/biogeochemistry and subsurface science
  - Science of interfacial phenomena

- Unparalleled capabilities:
  - Integrated experimental and supercomputing capabilities enable users to study molecular-level processes underpinning energy and environmental challenges
  - 60+ leading-edge capabilities and expert staff are available to university, DOE laboratory, and industry scientists
BER Research: Systems Biology of Hydrogen Production

Objective: Provide integrative, systems-level understanding of hydrogen production by photosynthetic and fermentative microbes

- Identification of novel genes, enzymes, and biochemical pathways relevant to hydrogen metabolism
- Understanding metabolic and regulatory networks involved in biological hydrogen production by microbes or microbial communities
- Development of genetic tools and research capabilities for a broader range of hydrogen-producing model organisms
- Enable directed metabolic engineering approaches for enhanced hydrogen production
Tracking Temporal Integration of Metabolic Cycles in Cyanobacteria

Objective:
- Study regulation of carbon, nitrogen, and hydrogen metabolism in *Cyanobyce*, a genus of photosynthetic marine bacteria.

Approach:
- Compare hydrogen production among strains.
- Analyze expression and regulation of genes during hydrogen synthesis.
- Make targeted mutations to genes involved in hydrogen production.

Outcomes:
- Understand regulation of hydrogen production.
- Development of new genetic tools to advance *Cyanobyce* as a model organism for hydrogen production.
Metabolic Network Analysis and Annotation of Gene Function in Algae

Objective:

- Develop a new approach to build metabolic network models and study gene function in the alga *Chlamydomonas reinhardtii*

Approach:

1. Computational prediction of gene function
2. Construct metabolic network model
3. Verify gene expression

Outcomes:

- Enables new metabolic engineering approaches for enhancing algal hydrogen production
- Provides a new systems-based method applicable to any organism with a sequenced genome.

Hydrogen Production & Consumption In Complex Microbial Communities

Objective:
- Examine conversion of woody plant material to hydrogen by the symbiotic microbial community of wood-feeding beetles

Approach:
- Identify resident microbes by metagenome sequencing
- Characterize chemical conditions in gut compartments
- Determine which microbes are involved in hydrogen production

Outcomes:
- Understand highly efficient conversion of biomass, production of hydrogen, and capture of energy by symbiotic system
- Identify new organisms, enzymes, and biochemical pathways for hydrogen production
Biological and Environmental Research

Complex systems science to meet DOE mission needs in bioenergy, climate, and the environment
Thank you!

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