Biofuels Research
Science for America’s Energy Future

David G. Thomassen, Ph.D.
Chief Scientist
Office of Biological & Environmental Research
We are big consumers

- We use a lot of gasoline - ~150 billion gallons annually
- We import a lot of oil (from places we don’t want to) - ~60%
- Today we make ~13 billion gallons of ethanol mostly from corn
- There isn’t enough corn - ~44 billion gallons if we used all corn to make ethanol
- Energy in 1 gallon of gas requires 1.4 gallons of ethanol
- America has 1/3 of the world’s automobiles
- America uses 25% of the world’s oil
Bioenergy Research is a MultiAgency Effort

Interagency Biomass Research and Development Board

The interagency Biomass Research and Development Board was created by the Biomass Research and Development Act of 2000 and is comprised of numerous Federal Departments and agencies.
Research Challenges Exist at Every Step

Feedstock Production ➔ Feedstock Logistics ➔ Biofuels Production ➔ Biofuels Distribution ➔ Biofuels End Use

Sustainability

Environment Health & Safety

Crosscutting Action Areas
Lignocellulosic Biomass to Fuels

Challenges (and this is only a few of them)

- Cellulose and hemicellulose are occluded by lignin
- Lignin is recalcitrant to depolymerization
- Inhibitors released from biomass
Steps in cellulosic ethanol production

Today’s Biorefinery

From: Breaking the Biological Barriers to Cellulosic Ethanol
Improvements through Research

From: Breaking the Biological Barriers to Cellulosic Ethanol
Properties of Optimal Bioenergy Feedstocks

- High yield (>15 tons/acre/year)
- High water use efficiency
- Low input (e.g., fertilizer, tillage, pesticides)
- High conversion efficiency
- Sustainable
- Stable quality and quantity from year to year

Crop residues will play a part, but the need for large-scale production favors dedicated energy crops.
DOE Bioenergy Research Centers
Multi-institutional partnerships

DOE Joint BioEnergy Institute (JBEI)
- Lawrence Berkeley National Laboratory, Berkeley, California
- Carnegie Institution for Science at Stanford University, Palo Alto, California
- University of California, Berkeley
- Lawrence Livermore National Laboratory, Livermore, California
- Sandia National Laboratories, Livermore, California
- University of California, Davis
- Sandia National Laboratories, Albuquerque, New Mexico

DOE Great Lakes Bioenergy Research Center (GLBRC)
- Pacific Northwest National Laboratory, Richland, Washington
- Iowa State University, Ames
- University of California, Berkeley
- Illinois State University, Normal
- Lucigen Corporation, Middleton, Wisconsin
- Oak Ridge National Laboratory, Oak Ridge, Tennessee
- GLBRC Partner
- Michigan State University, East Lansing

DOE BioEnergy Science Center (BESC)
- Oak Ridge National Laboratory, Oak Ridge, Tennessee
- Cornell University, Ithaca, New York
- Dartmouth College, Hanover, New Hampshire
- Verenium Corporation, Cambridge, Massachusetts
- Mascoma Corporation, Boston, Massachusetts
- Brookhaven National Laboratory, Upton, New York
- Virginia Polytechnic Institute and State University, Blacksburg
- University of Tennessee, Knoxville
- North Carolina State University, Raleigh
- University of Georgia, Athens
- Georgia Institute of Technology, Atlanta
- ArborGen, Summerville, South Carolina
- University of Minnesota, St. Paul
- The Samuel Roberts Noble Foundation, Ardmore, Oklahoma
- National Renewable Energy Laboratory, Golden, Colorado
- Washington State University, Pullman
- University of California, Riverside
- Ceres Thousand Oaks, California

Symbols:
- Blue square with text: DOE Joint BioEnergy Institute (JBEI) and Partners
- Red triangle with text: DOE Great Lakes Bioenergy Research Center (GLBRC) and Partners
- Green circle with text: DOE BioEnergy Science Center (BESC) and Partners
BioEnergy Science Center

- **Focus:** Overcoming “recalcitrance” (resistance of plant fiber, or lignocellulose, to break down into sugars)
  - Gene discovery for *recalcitrance* in switchgrass and poplar
  - Use of synthetic biology to re-engineer the *cellulosome*
  - Long-term “**consolidated bioprocessing**” goal: One microbe or microbial community for processing plants into fuel
  - Opportunity to test discoveries in a *demonstration biorefinery* being constructed by the state of Tennessee
Joint BioEnergy Institute

- Focus: Model crops (*Arabidopsis* and rice) for rapid advances that can be transferred to bioenergy crops
  - **Modifying lignin** to change its monomer composition for easier degradation and access to cellulose
  - Using ionic liquids for room-temperature biomass pretreatments
  - Using **synthetic biology** to look beyond ethanol to green gasoline, diesel, and jet fuels
  - Connecting with the **Bay Area Biotech Community** (a hub of bioenergy technology and venture investment)
Great Lakes Bioenergy Research Center

• Focus: Wide range of plants, including models and potential bioenergy crops (approach leverages the agronomic orientation of the two universities)
  – Engineering plants to incorporate lignin “zippers” and to produce more starches and oils for biodiesel
  – Developing alternative approaches to fuels: Microbial biorefineries that use sunlight and biomass to generate hydrogen, electricity, or high-energy chemicals
  – Investigating the sustainability of biofuel production by studying the environmental and socioeconomic dimensions of a biofuels economy
Joint Genome Institute and Bioenergy

Cellulosic feedstock development
- Poplar
- Maize and corn stover
- Switchgrass
- Brachypodium
- Sorghum

Cellulose and lignin degradation
- Termite hindgut microbiota
- White rot fungus
- Clostridium thermocellum
- Saccharophagus degradans
- Acidothermus cellulolyticus

Fermentation with ethanol-producing organisms
- Saccharomyces cerevisiae
- Zymomonas mobilis
- Thermoanaerobacter ethanolicus
- Pichia stipitis

Cellulosic materials

Sugars

Bioethanol
Biofuel Sustainability

- **Economic**
  - Profitable

- **Environmental**
  - Carbon negative (climate stabilizing)
  - Nutrient, water conservative
  - Biodiversity benefits

- **Social**
  - Food, energy security
  - Rural community health

Sustainability - What do we know?

1. Substantial land requirements (ca. 75-100 M ha US)
2. Possible to provide multiple benefits (ecosystem services)
3. Best outcomes will depend on
   - Choice of crops (e.g. annual vs. perennial)
   - Management practices
   - Location – prior crop history
4. We know what’s needed
   - Systems level science understanding
   - Framework that includes human interactions
   - Willingness to incentivize environmental performance
Diverse Bioenergy Feedstocks = Diverse Research Needs

From: Billion ton Vision, DOE & USDA 2005
Geographic distribution of biomass crops

- Hybrid Poplars
- Switchgrass
- Sorghum
- Switchgrass
- Hybrid Poplars
- Switchgrass
- Willows
- Hybrid Poplars
- Miscanthus
- Pine
- Sorghum
- Sweetgum
- Switchgrass
- Energy Cane
- Eucalyptus
- Pine
Marginal Farmland in the US

75 million ha once farmed, no longer in production (or developed)
@ 50% re-conversion, 20 tons/ha = 750M tons
A Path Forward for Energy from Biomass

A joint SC / EERE workshop
Biomass Program Mission and Objectives

Program Mission

Develop & transform renewable/abundant, non-food, biomass resources into sustainable, cost-competitive, high-performance biofuels.

Focus on targeted research, development, and demonstration

- Support through public and private partnerships
- Deploy in integrated biorefineries

Program Performance Goals

- Make cellulosic ethanol cost competitive at a modeled cost for mature technology: $1.76/gallon by 2012
- Help create an environment conducive to maximizing production and use of biofuels, 21 billion gallons of advanced biofuels per year by 2022 (EISA)
Key Accomplishments and Deliverables
Integrated Biorefineries

Expediting Commercialization

Commercial-Scale Biorefineries (up to $272 M)
- Four cost-shared, integrated biorefinery demonstrations to produce 98 million gallons of cellulosic ethanol in 5 years with variety of conversion technologies and cellulosic feedstocks

10%-Scale Biorefinery Validation (up to $210 M)
- Cost-shared, integrated biorefinery demonstrations using cellulosic feedstocks to produce renewable fuels at one-tenth of commercial scale
- Eight projects now in progress
Key Accomplishments and Deliverables

Recent Solicitations

Advanced Biofuels

- Integrated Pilot-Scale or Demonstration-Scale Biorefinery for Advanced Biofuels
  - Up to $480M over 6 years for 5-12 projects
  - Pilot-Scale requires >20% cost share
  - Demo-scale requires >50% cost share

Feedstock Logistics

- Integrated Feedstock Logistics Demonstration
  - Up to $15M over 3 years for up to 3 projects
  - Requires >20% cost share
  - Projects to be awarded end of fiscal year
Key Stakeholder Relationships

Biodiversity ($1.1 million in FY09)

- Working with Conservation International ($1.1 million in FY09) to:
  - Identify land that should not be developed into biofuel crops
  - Conduct pilot studies to identify best places for biofuel crops
  - Implement standards for biofuel crop production

Standards Development

- Participating in Council for Sustainable Biomass Production ($50K in FY09) to develop principles and standards for bioenergy feedstocks
- Providing data and analysis to inform a variety of international and domestic discussions on sustainability standards
  - Roundtable on Sustainable Biofuels
    - Participation from NREL and DOE headquarters
  - Global Bioenergy Partnership (GBEP)
    - Effort led by State Department to develop methodology for GHG emissions estimates and global sustainability criteria
    - Information on activities at (http://www.globalbioenergy.org/)
Key Stakeholder Relationships
Biofuels Interagency Working Group

On May 5, 2009, President Obama signed the directive establishing a new working group to be chaired by the Secretaries of Energy and Agriculture and the Administrator of the EPA.

The group will work with the National Science and Technology Council’s Biomass R&D Board on:

– Creating a *biofuel market development program* to boost next-generation biofuels, increase use of flex-fuel vehicles, and assist retail market development

– Coordinating infrastructure policies

– Identifying policies to promote sustainable production of biomass feedstocks

– Restructuring investments in renewable fuels to preserve employment, accelerate biofuel production, and reduce dependence on fossil fuels

“If we are to be a leader in the 21st century global economy, then we must lead the world in clean energy technology.” -- President Barack Obama
Thank you!

David Thomassen
David.Thomassen@science.doe.gov
http://science.doe.gov/ober