Great Lakes Bioenergy Center

- Led by the University of Wisconsin-Madison with Michigan State University as the major partner.
- The mission of the GLBRC is to perform the basic research that generates technology to convert cellulosic biomass to ethanol and other advanced biofuels.
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MSU GLBRC Metrics

Since 2007

- Patents and patent applications
  - 21 patents
  - 32 patents pending

- Licenses and Options
  - 16 licenses
  - 6 options
Great Lakes Bioenergy Center
Sustainability Research

Make the fundamental discoveries needed to design sustainable biofuel systems and provide a capacity to model alternative biofuel systems

❑ Economic – farmer, refiner, policy
❑ Social – energy and food security
❑ Environmental – climate, conservation, and biodiversity
Understanding Sustainability Research

What are the environmental implications of widespread biofuel feedstock cultivation?

Of greatest concern:

- Is there a net climate benefit when all GHG are considered?
- How much carbon debt is created on conversion to biofuel crops?
- To what degree will conservation and biodiversity suffer?
- What are the water and reactive nitrogen costs?
- Is there a way to avoid food vs. fuel competition?

Global warming impact (GWI) of alternative cellulosic cropping systems (20 years post-establishment) shows substantial climate benefit.
Biomass Supply Chain Modeling

Farmgate price: $40/dry ton
Weighted ethanol selling price: $2.18/gal
Total Ethanol Produced: 4.5 billion gal/yr

Farmgate price: $80/dry ton
Weighted ethanol selling price: $2.46/gal
Total Ethanol Produced: 42 billion gal/yr

All biomass is local: “average” values do not provide much useful information
Biomass Regional Spatial Modeling – Marginal Lands Potentials

Regional yield gap analysis
- Follow-on from earlier analysis of regional marginal lands
- Simulated yields and soil carbon gain for marginal lands at 0.5 ha resolution at multiple N rates to find optimal fertilizer need

Two questions:
- What are the consequences of additional fertilizer nitrogen on reactive nitrogen loss to the environment?
- Can carbon sequestration offset the GHG cost of additional reactive N?
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Plants Research

Develop sustainable, productive energy crops that can easily be processed into fuels and bioproducts.

- Increase biomass fuel value
- Improve sustainability
- Reduce recalcitrance
Increase Biomass Fuel Value

- Manipulate levels and composition of hemicellulose in the cell wall
  - Hexose-rich hemicelluloses
  - Promote production of mixed-linkage glucan (MLG) in parenchyma tissues of model grasses (Brachypodium, corn, and sorghum)
Increase Biomass Fuel Value

- Alter/enhance/produce oils in vegetative tissues
- Novel acyltransferase that synthesizes low viscosity oils – acetyl-triacylglycerols (AcTAGs)
  - Lower melting points and viscosity
  - Drop-in fuel
- Lipid droplets as an engineering platform for alternate fuels and coproducts
  - Terpenoids
    - Biopesticides, allelochemicals, and herbicides
    - Flavor, fragrance, and neutraceuticals
    - Industrial feedstocks
Improve Productivity and Sustainability

- Increase productivity of native grasses by delaying flowering time
  - Identify flowering time genes to inform work on biofuel crops
  - Switchgrass breeding

Switchgrass selection for winter-hardy lowland ecotypes that flower later.
Reduce Recalcitrance

- Alter lignin
- "Zip-lignin" technology introduces more easily-cleaved ester bonds into the lignin backbone
- FMT gene doubles the sugar yield from poplar biomass
Xylem-specific promoters
- Increased cellulose biosynthesis
- Increased gluco-mannan content
  - Lower processing requirements
- Increased starch in plant leaves at harvest
- Increased methylesterification of homogalacturonan in the plant cell wall
  - Improved digestibility
  - Larger plants
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Deconstruction Research

Develop chemical and enzymatic methods to release monomers and short oligomers from lignocellulosic biomass

- Pretreatments to open the matrix of plant cell wall polymers
- Lignin streams
- High-resolution imaging of cell walls
Two Ammonia-based Pretreatments

- Work well with grasses
- Ammonia Fiber Expansion (AFEX)
  - Can easily pelletize biomass
- Extractive Ammonia (EA):
  - Generates separate lignin stream
Copper-Catalyzed Alkaline Hydrogen Peroxide (Cu-AHP)
- Adding Cu to AHP improves performance
- Works very well with woody biomass
- High glucose yields and separate lignin stream
- Lignin is largely unmodified

Biomass: Hybrid Poplar
24 h pretreatment (30°C, 1 atm)
72 h enzymatic hydrolysis

Glucose yields (%)
Lignin Valorization

- Targets for lignin extraction:
  - High yield
  - Minimal chemical modifications
  - Compatibility with downstream processes
- Deconstruct extracted lignin into smaller aromatic fragments

Diagram: Potential market value (£/ton) vs. Production / market volume (kton/year)

Figure courtesy Richard Gosselink
Cell Wall Imaging

- *In situ* imaging at nanoscale resolution and real-time changes during biomass deconstruction processes
- Currently using to correlate digestibility of zip-lignin poplar lines to changes in cell wall ultrastructure
- Unique technology

Wild type | Line 5
---|---
Lignin (1600 cm⁻¹) | Lignin (1600 cm⁻¹)
GFP-CBM3 Antibody binding | GFP-CBM3 Antibody binding

A | D | G | J
B | E | H | K
C | F | I | L

Untreated | Alkaline treatment | Cu-AHP treatment

Confocal and fluorescence microscopy of Cu-AHP treated zip-lignin WT and Line 5.

www.glbrc.org
Early Deconstruction Area Technologies

- Mixture to induce cellulolytic enzymes for deconstruction of lignocellulosic biomass
  - Reduces cost
  - Can be produced in-house
- Alpha-xylosidase enzyme
  - Increase yield of fermentable sugars
Future Directions

- Comprehensive Integration of the Field-to-Product Pipeline
  - Modeling of field-to-product pipelines
  - Mitigate the impact of feedstock variability on deconstruction and conversion
  - Improve methods for creating lignin-derived bioproducts
  - Optimize production of terpeniod biofuels and bioproducts

Field-to-Product Integration
Future Directions

Sustainable Production of Bioenergy Crops with Desirable Traits

- Increase yield and quality of bioenergy crop biomass
- Improve switchgrass productivity
- Maximize bioenergy crop performance on marginal lands
Future Directions

Efficient Conversion of Biomass into Specialty Biofuels and Bioproducts

- Develop deconstruction and separation techniques that optimize C yield
- Reprogram microbial C flux to specialty biofuels
- Synthesize bioproducts from conversion residue
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