BioFuels Research Opportunities/Needs

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1908 Henry Ford’s Model T was powered by ethanol generated from bioethanol plants he owned in the midwest was partnered with Standard Oil.

1898 Rudolph Diesel demonstrated his compression ignition engine at the World's Exhibition in Paris with peanut oil.

G. W. Bush 2006 State of Union Address “America is addicted to oil, which is often imported from unstable parts of the world. The best way to break this addiction is through technology…”
Brief Biofuels: Perspective

Energy/Transportation Fuels

Costs

Options

Benefits

Modern Lifestyle
Economy
Environment
Brief Biofuels: Perspective

US: Currently
Bioethanol 2%
Biodiesel 0.01%

BioFuel Resources
- USA - Corn
- Brazil – Sugar Cane
- Europe – Sugar beet, Potato
  Rapeseed/sunflower

Methyl tert-butyl ether (MTBE)
Additive in unleaded gasoline.

U.S.A. Bioethanol
MM Gal. Annual

Total Renewable Fuels Consumption for Transportation Three Cases, 2003-2020 (Billion Gallons/Year)

RFS Schedule
6
5
4
3
2
1
0

Reference
87% Reduction in MTBE
Cellulosic Ethanol Credit
Biodiesel
Reference
14 States Ban MTBE Starting in 2012
Additional 5 Northeast States Ban MTBE

Methyl tert-butyl ether (MTBE)
Additive in unleaded gasoline.
Biofuels Future
Biomass Resources

Exhibit 13: OPEC spare capacity essentially gone


Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply

April 2005

Today
Amylase
Yeast

Future
Biomass

Acid Catalyst or Enzymes
Fermentation

H₂
H₃C
C
OH

H₂
H₃C
C
OH

Cellulosic Ethanol Biofermentation
Corn Ethanol
Gasoline
Electricity

Fossil Energy Ratio (FER) = Energy Delivered to Customer / Fossil Energy Used

Projected: 10.3
Current: 1.34

Biofuels as replacement for fossil fuels.
Biofuels Future

Biomass Resources

Lower Cost

No Competition with Food Demand

Higher Availability

Global Forest Cover

Cellulose
Polymer of β-(1,4)-glucan
Degree of Polymerization ~300 – 15,000
Production: ~ 35 – 50%

Lignin
Polymer Derived from Major Global Biopolymers

Hemi Cellulose
Short chain branched, substituted polymer of pentoses and hexoses
Degree of Polymerization ~70 - 200

Production: ~ 20 -30%
Production: ~ 15 – 30%

Global Forest Cover Legend
- Open or Fragmented Forest
- Other Woody Land
- Closed Forest
- Other land cover
- Water
BioResource | % | ~ Lignin | Hemicellulose | Cellulose
---|---|---|---|---
Softwood | 27 | 28 | 39 |
Hardwood | 25 | 30 | 40 |
Corn Stover | 18 | 22 | 38 |
Wheat Straw | 23 | 21 | 38 |
Fine Paper | - | 20 | 80 |
Switch Grass | 18 | 21 | 31 |

*Need to utilize all Bioresources BioPolymers*
Biofuels Future
Integrated Biorefinery

The biorefinery is a facility that integrates biomass conversion processes and equipment to produce fuels, power, and chemicals from biomass. It fully utilizes all components of biomass to make a range of foods, fuels, chemicals, feeds, materials, heat, and power in proportions that maximizes sustainable economic development.

The Path Forward for Biofuels and Biomaterials. Ragauskas, A.J.; Williams, C.K.; Davison, B.H.; Britovsek, G.; Cairney, J.; Eckert, C.A.; Frederick, W.J., Jr.; Hallett, J.P.; Leak, D.J.; Liotta, C. L.; Mielenz, J.R.; Murphy, R.; Templer, R.; Tschaplinski, T. Science (2006), 311(5760), 484-489
Biofuels
Research Challenges: Plant Science

Research Objective
“More, Bigger, Better;” the mantra of modern consumerism, ironically, summarizes the goals of research aimed at modifying plants for use in sustainable biomass production

- ~ 8 dry Mg Ha-1 yr-1 for willow in Sweden to 10-22 dry metric tons per hectare yr-1 in U.S. for short-rotation woody crops, commercial plantations in Brazil up to 20 dry Mg ha-1 yr-1.
- Manipulating photosynthesis genes to increase the initial capture of light energy
- Manipulation of genes involved in nitrogen metabolism
- Overexpressing a Glutamine Synthase (GS1) gene transgenic poplar, tree height increased to 41% greater than control plants
- Repressing a single lignin biosynthetic gene, 4 CL, resulted in a reduction in lignin content with a concomitant increase in cellulose
Biofuels
Research Challenges: Plant Science

Research Objective
“More, Bigger, Better;” the mantra of modern consumerism, ironically, summarizes the goals of research aimed at modifying plants for use in sustainable biomass production

- Lignin biosynthetic gene CCR is downregulated in poplar, the cellulose component of the plant cell wall is more easily digested by the bacterium Clostridium cellulolyticum, and twice as much sugar is released
- Enhanced plant oils, waxes, naval stores
- Endogenous production of polysaccharide hydrolyase enzymes could also be coupled with enhanced plant biomass production made possible by recent advances in molecular farming
  > Soil productivity/management
  > Collection systems
BioFuels
Research Challenges Conversion

Bioethanol <<<< Glucose <<<<< Cellulose << Biomass

Efficient Depolymerization of Cellulose – Glucose

• Biomass Pretreatments
  – Conventional, Organic Solvents, Steam Explosion
  – Ionic Liquids, Nearcritical Water, Gas Expanded Liquids

• Acid Catalyzed Hydrolysis of Cellulose
  – Catalysis
  – Conditions
  – Reduction/elimination of fermentation inhibition by-products
Biofuels

Research Challenges: Biomass Characterization

Advanced Spectroscopic Bio-Analysis – High Volume

- Enhanced biomass production/acre
- Reduced perception of nearest neighbor
- Manipulating photomorphogenic responses of phytochrome Red/FR light perception system
- Greater carbon allocation to stem diameter vs. height growth
- Less extensive root system to maximize aboveground biomass
- Optimal nitrogen acquisition and use
- Increased photosynthesis
- Optimized photoperiod response
- Optimized crown/leaf architecture
- Regulated dormancy
- Delayed leaf senescence
- Pest/disease resistance, drought/cold tolerance
- Floral sterility

Controlled and readily processable carbohydrates
- Carbohydrates: Controlled and readily processable cellulose, hemicellulose, and lignin. Tailored biomass composition with value-added chemicals

Need for Rapid, Inexpensive Detailed Topochemical Characterization of Biomass Initial/Processed

- **Cellulose** – Structure, DP, Ultrastructure, Location
- **Hemicelluloses** – Chemical constituents, Structure, DP, Location
- **Lignin** – Chemical constituents, Structure, DP, Location
- **Extractives** – Structure
Biofuels
Research Challenges: Separations

Extraction of Value Added Chemical
- Neutraceuticals
- Drugs
- Bioactive agents

Value Added Materials
- Nanocellulose/hemicellulose
- Lignin for carbon fibers
- Chemicals/Polymers

BioFuels
- Ethanol
- Butanol
- Dimethyl ether
- Biodiesel
- Biogasoline

Wang et al., Argonne 1999

DOE
BioFuels
Research Challenges Conversion

Bioethanol <<< Glucose <<< Cellulose <<< Biomass

Efficient Depolymerization of Cellulose – Glucose

- Cellulase Hydrolysis of Cellulose
  - Enhanced thermostability
  - Improved hydrolysis
  - In-situ Expression
  - Cellulose ultra-structure

[NREL]
BioFuels
Research Challenges Conversion

Bioethanol \(<<<\) C6/C5 Sugars \(<<<\) Hemicellulose \(<<\) Biomass

C6 C5 Fermentation Research Issues:
- Minimize fermentation inhibitors such as furans, phenolics, carboxylic acids
- Ability to efficiently ferment C6 and C5 sugars
- Manipulate ethanol and sugar tolerance fermentation
BioFuels
Research Challenges Conversion

Chemical Pathway to Fuel Precursors

Sugar Research Needs
- Decarboxylation Catalyst
- Dehydration Catalyst
- Hydrogenation Catalyst

Lignin Research Needs
- Depolymerization Catalyst
- Hydrodeoxygeneation Catalyst

$n: 150 - 7500$

Cellulase

Potential Catalytic
Loss of CO₂ and H₂O

Polymers

$C10 – C22$
BioFuels
Research Challenges Conversion

Biomass

Biomaterials – Biochemicals

Biofuels

Gasification

Power
Heat
Electricity

Mixed Alcohols
Waxes and Diesel
Olefins and Gasoline
MTBE
Acetic Acid

SynGas
CO + H₂

Fischer-Tropsch

Formaldehyde

Ethanol

Aldehydes

Acetic Acid

Carbonylation

CH₃OH + CO

Co, Rh

MTB
Acetic Acid

Isomerization

H₃C-CH₂-CH=CH₂

Co

M100
M85
DMF

Direct Use

Acidic ion exchange

DME

Al2O3

Zeolites

MTO

MTG

Olefins

Gasoline

MTBE

Alcohols

Acetic Acid

Carbonylation

CH₃OH + CO

Co, Rh

Acetic Acid

Olefins

MTBE

Research Needs

• Gas cleanup/tars
• New catalyst
• Biological ‘Fisher Tropsch’ routes
BioFuels
Social Policy Challenges

Biorefinery – Biofuels Has Arrived at a Key Tipping Point

• Biorefinery concepts can/need to be evaluated for environmental as well as their technical and economic potential.

• Such environmental impact assessments are best conducted using Life Cycle Assessment – LCA

• LCA is a systems analysis tool to describe the ‘cradle-to-grave’ environmental impacts of products and processes
BioFuels
Educational Challenges

Sustainability, Environmental, Energy Security
• Societal Issues
• Student Issues – K-12, Undergraduate, Graduate
• Opportunity of Lifetime to re-engage students to Science and Engineering

• Need to introduce additional concepts in
  ➢ Biomass Chemistry/Biochemistry
  ➢ Biomass Biosynthesis
  ➢ Systems Biology
  ➢ Chemistry/Biochemistry of Cellulose, Hemicellulose, Lignin
  ➢ Green Chemistry of Processing Biomass
  ➢ Biorefinery – Sustainability
  ➢ Analytical Chemistry of Bioresources
BioFuels - Challenge

Grand Challenge for the New Millennium

Development of Sustainable, Renewable BioFuels and BioMaterials for 9 Billion People by 2050

Equivalent

1961: J.F. Kennedy “The goal, before this decade is out, of landing, a man on the moon and returning him safely to the earth”

1990: Human Genome Grand Challenge
W.J. Bryan
Destiny is not a matter of chance, it is a matter of choice, it is not a thing to be waited for, it is a thing to be achieved

Thank You!