A research agenda for making biomass a sustainable source of transportation fuels

John Sheehan
National Renewable Energy Laboratory
Golden, Colorado, USA

Presented at
Advanced Transportation Workshop
Stanford University
October 11, 2005
Outline

• Biomass
• The biorefinery
• Sustainable fuels from biomass
• Implications for research
Today the largest source of biofuels for transportation is corn, supplying 4 billion gallons per year of fuel ethanol.
Biomass Today

• Vegetable oil and animal fats offer opportunities for making diesel fuel substitutes
Biomass Emerging

• Post consumer wastes including urban wood waste, yard trimmings, municipal solid waste and recycled fats and greases
Biomass Emerging

- Agricultural residues such as corn stover, sugarcane bagasse and wheat straw offer an immediately available source of biomass for fuels, larger than traditional crops
Biomass Emerging

• The growing problem of forest fires offers a new opportunity to use the “excess fuel” removed for forest health management.
Energy crops offer a future of high volume, sustainable production of biomass for fuels:

- Trees
Biomass Future

• Energy crops offer a future of high volume, sustainable production of biomass for fuels:
  • Grasses
Biomass chemistry today and tomorrow

<table>
<thead>
<tr>
<th>Today grains, oilseeds</th>
<th>Sugars Starch Lipids</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emerging and future MSW, residues, energy crops</td>
<td>Cellulose Hemicellulose Lignin</td>
</tr>
</tbody>
</table>
The biorefinery
Something for everyone?

FUELS
- Ethanol
- Fischer-Tropsch Liquids

POWER
- Electricity
- Heat

CHEMICALS
- Plastics
- Solvents
- Chem Intermediates
- Phenolics
- Adhesives
- Furfural
- Fatty Acids
- Organic Acids
- Paints
- Dyes
- Detergents

FOOD & FEED

NREL National Renewable Energy Laboratory
The biorefinery
Two main “flavors”
Sustainable Biofuels

• Pimentel (and Patzek’s) Complaint
  • “Negative return on energy”
  • Environmentally unacceptable
  • Economically burdensome
  • Unethical use of land
The Energy Balance

Energy Efficiency of Fully Integrated Thermochemical and Biochemical Technologies in a Biorefinery

- Power: 49%
- Thermochemical Fuels and Power: 57%
- Bioconversion and Power: 68%
- Biochem/Thermochem Conversion Fuels and Power: 75%
- Petroleum Refinery: 85%

Percent Biomass Energy Efficiency
Environmental Acceptability

Nitrogen oxide life cycle emissions (grams NO\textsubscript{x} as NO\textsubscript{2} per mile)

- Total Ethanol Fuel: 1.854
- Total Gasoline: 0.149

Greenhouse Gas Emissions (grams CO\textsubscript{2} equiv per mile)

- Total Ethanol Fuel: -24.3
- Total Gasoline: 384.7
Economic Acceptability

Projected Ethanol Price ($/gal gasoline equiv)

Development of Biological Conversion Technology

- 2000: Cost for enzymatic hydrolysis process based on available performance data in the year 2000
- 2004: Cost based on performance data available in the year 2004
- Mid Term: DOE mid term target for enzymatic hydrolysis technology in 2010
- Mature: Mature technology for ethanol based on a single microbe capable of hydrolyzing cellulose and ethanol production

High and low range of wholesale gasoline price

- $5.27 for 2000
- $3.78 for 2004
- $1.62 for Mid Term
- $0.91 for Mature

National Renewable Energy Laboratory
Ethical Land Use

Land Requirements for Current Total U.S. Light and Heavy Duty Fuels: Current Switchgrass Yield at 5 t/ac/yr

- Status Quo: 1088 million acres
- Ag residue utilization: 1005 million acres
- Forest resources: 940 million acres
- Improved conversion technology: 313 million acres
- Improved current yield: 157 million acres
- Improved vehicle efficiency: 63 million acres
- Coproduction of protein: ~400 million acres in U.S. Agriculture

Millions of Acres
A sustainable vision

Source: NRDC, Growing Energy, December 2004
What are the implications of this sustainable vision for the role of biomass for future research?
Importance of a sustainable vision for biomass

• “The United States does not have to rely on oil to drive our economy. We can replace much of our oil with biofuels...[which] can also slash global warming emissions, improve air quality, and expand wildlife habitat”
Importance of sustainable vision for biomass
Rethinking the biorefinery

Two Platforms for the Biorefinery

- Biochemical Conversion
- Thermochemical Conversion
- Products
Rethinking the biorefinery

Biorefinery Options including Integrated Biochemical and Thermochemical Conversion

Biochemical Conversion

Combined Heat and Power

Thermochemical Conversion

Products

National Renewable Energy Laboratory
Rethinking the biorefinery

The Integrated Biorefinery
The right tool for the right job
Biological processing of biomass followed by Thermochemical processing of non fermentables
Rethinking the biorefinery

The Integrated Biorefinery
The right tool for the right job
A more flexible vision
The future of bioprocessing

Demands a new level of fundamental research to go from this...
The future of bioprocessing

...to a consolidated process in which biocatalysts offer multifunctionality
Research to understand biomass

• Efficient “deconstruction” of biomass requires a more thorough understanding of physical and chemical structure of biomass
Putting biotech to work

Protein engineering for better biocatalysts
Putting biotech to work

New organism discovery for novel genes
Putting biotech to work

Metabolic engineering to broaden substrate/product capability
Other biotech opportunities

- Engineering photosynthetic efficiency and H₂ production in algae
- Algae for oil production
Other biotech opportunities

- Engineered plants for more productive and sustainable use of land and enhanced compatibility with conversion processes
Thermochemical technology

- The “omnivorous” option for utilizing biomass
- Syngas to fuels
- Synergies with bioprocessing
Process Engineering
Process design
Process development
Process integration
Separations
Energy efficiency

Bioethanol Gasification
Sustainable design
Life cycle perspective
Overall resource capacity
Economic/quality of life impacts
Land Use
The social sciences

Making sound political choices that move us toward a sustainable energy future