Biotechnology: New Tools for Sustainable Biofuels Production
Some Industrial and Environmental Section Members
Global Energy Demand: Why We Can’t Afford for Biofuels to Fail
The Emerging Future: Duality in Feedstocks and Processes

**KEY COMPETENCIES**
- Catalysis
- Chem Engineering
- Material Science

**Petroleum Based**
- Oil Well
- Refinery
- Petrochemicals
- Heat
- Pressure
- Catalyst

**Renewable Resources Based**
- FARM
- Commodity Processor
- Carbohydrate
- Oils
- Feed / Food
- Plant Expression
- Specialty Processor

**Energy**
- 97%

**Feed / Food**
- 85%
- 25%
- 15%
- 75%
- 80%
- 20%

**Bioprocessing**
- 85%
- 15%
- 75%
- 80%

**KEY COMPETENCIES**
- Biotech Basics
- Bioprocessing
- Chem Engineering
- Material Science
How is Biotechnology Making Biofuels More Sustainable?

1. Agriculture biotechnology is improving existing crops and developing new dedicated energy crops

2. Industrial biotechnology is improving biorefining technology and developing new renewable fuels
Biotechnology is Improving Biorefining

- INDUSTRIAL BIOTECHNOLOGY
  - Improving conventional ethanol
  - Enabling commercial scale cellulosic ethanol
  - Developing bio-butanol
  - Researching renewable hydrocarbons
Microbes and Fungi Found in Nature--Used to Make New Enzymes

Source: NOVOZYMES
Conventional Ethanol Improvements

- More efficient grain fractionation increases efficiency and creates a new cellulosic feedstock stream
- New biotech enzymes for cold “no cook” saccharification—increase efficiency and reduce energy inputs and CO2 outputs
- Increases ethanol yield by 6% per bushel of corn
POET Advanced Fractionation Systems Approach

- Corn Dry mill
- Advanced fractionation process
- Endosperm
- Biotech Enzymes
- No-cook fermentation
- Ethanol

Germ
For cattle feed

Bran
To Cellulosic Bioprocessing

Advanced Fractionation Ethanol Unit with Enzyme Cold “No-Cook” Fermentation
Enabling Cellulosic Ethanol

- Cellulase enzymes are the key to cellulosic ethanol

- These enzymes are produced by GEMs and they convert the tightly bonded sugars in cellulose plant matter into individual 5 carbon and 6 carbon sugars.

- These sugars (such as glucose) are then available for fermentation to ethanol by other microorganisms.
One source of new cellulase enzymes

The Pacific Dampwood Termite
Zootermopsis angusticollis

Courtesy of Jared Leadbetter, CalTech, Pasadena, CA
Cellulase: Molecular Machine for Energy Conversion

Converting Cellulose to Glucose
Abengoa Bioenergy Facility in Spain
Currently under construction to be completed in mid-2008

Salamanca cellulosic biomass-to-ethanol plant
Abengoa Bioenergy
Salamanca, Spain

• Will produce 5 million liters per year (1.3 million gallons)
• Wheat straw feedstock
• Construction complete by mid-2008
• Biotech process not thermochemical
Abengoa Bioenergy
Planned Facility in Kansas
2007-2008

- 100 million gallon capacity
- 90 million gallons from corn starch
- 10 million gallons from wheat straw
- Will have energy island that utilizes corn stover for boiler fuel
Beyond Ethanol—Longer Chain Alcohols and Hydrocarbons

- Involves using microbes and synthetic biology to build new microorganisms that can produce higher value molecules for use as transportation fuels.

Examples

- Amyris—modular design of metabolic pathways.
- LS9—combing genomics, proteomics and synthetic biology.
- Gevo—butanol and other molecules.
Gevo Process
Fuel and Chemical Biorefinery

Process Overview

Bio-processing

Chemical processing

Feedstock

Bio-catalyst

Enzymes

Nutrients

Milling

Fermentation

Distillation

Separation

Drying

2008 industry focus

Gasoline Blend stock

Chemical Precursor

Feed Products

Jet Fuel

Diesel Blend stock

Iso-Octane

Next steps based on iso-Butanol

Diesel

Chemical Products

Retrofit of a corn dry mill ethanol plants

Creates market options

Future: Any bio-based sugar source

Mar '08
Renewable Gasoline

- Involves using microbes and rapid enzymatic pathway construction techniques to build new microorganisms that can produce higher value compounds (hydrocarbons) for use as transportation fuels.

Examples

- **Amyris**—modular design of metabolic pathways
- **LS9**—combing genomics, proteomics and synthetic biology
History of Oil Refineries
Instructive for Biorefinery Development

1853—Łukasiewicz was the first to distill kerosene from seep oil

1. 1859—Principal refined product from petroleum was kerosene which quickly replaced whale oil in the United States. (disruptive technology)

2. 1900—“horseless carriages” needed fuel. Distillation refining did not produce enough of it—only about 20 percent gasoline from a unit amount of crude oil.

3. 1913—Thermal cracking then doubled the efficiency of refining, to produce 40 percent gasoline per unit of oil. The refiners could then keep pace with automobile demand.

4. 1930’s—Catalytic cracking added to refining efficiency

5. Today—coking, steam cracking, alkylation, catalytic reforming, hydro cracking are used to maximize refinery outputs

6. Oil refining 155 years in development
Example of a Biorefinery--Blair, NE (Cargill Site)
We are Just at the Beginning of the Biorefinery Journey Not the End
Biotechnology is Improving Biofuels

- AGRICULTURAL BIOTECHNOLOGY
  - Improving crop yields
  - Increasing ethanol efficiency
  - Increasing crop hardiness and survival
  - Developing new dedicated energy crops
Corn Yields Increasing Yearly

Indiana Corn Grain Yield, 1866 - 2005

Source: USDA-NASS
No Till Farming can sequester carbon
CO2 Flux with Various Tillage Practices

1991 FALL TILLAGE CUMULATIVE CO₂ FLUX

- Plow Only
- Plow and Disk Twice
- Disk Only
- Chisel Only
- No Tillage

Source: D. Reicosky
USDA ARS, Morris, MN
Dedicated Energy Crops

- First Switch grass seed on market this year (Blade™)
- High biomass sorghum
- Miscanthus
- Others
High Biomass Sorghum

Ceres R&D Objectives
Expect to double the rate of improvement to biomass yields
Broader adaptability to cooler climates
Other agronomic & compositional improvements

R&D Collaboration with Texas A&M
Leading institution in high-biomass types
Switchgrass

Ceres R&D Objectives
- Biomass and establishment
- Composition
- Improved breeding systems
- Seed quality improvements
- R&D Collaboration with Noble Foundation
- Premier institute for breeding perennial grasses
Multi-stakeholder group involving academia, industry, NGOs and government, focused on biomass and second generation biofuels.
ACHIEVING SUSTAINABLE PRODUCTION
of Agricultural Biomass for
Biorefinery Feedstock

INDUSTRIAL AND ENVIRONMENTAL SECTION  HELPING THE BIOBASED INDUSTRY GROW
Achieving Sustainable Production of Agricultural Biomass for Biorefinery feedstock

- Some findings:
  - Corn stover and cereal straw are most likely cellulosic feedstock in the near term due to high per acre yields
  - Corn farmers could supply over 200 million dry tons annually within three to five years
  - Collection of 30% of current annual stover production would yield 5 billion gallons of ethanol
  - More no-till will be required on some farms to preserve soil fertility and allow for sustainable harvesting
Net energy of cellulosic ethanol from switchgrass


*U.S. Department of Agriculture—Agricultural Research Service, University of Nebraska,

Net energy yield (NEY) of 60 GJ·ha⁻¹·y⁻¹. Switchgrass produced 540% more renewable than nonrenewable energy consumed. Switchgrass monocultures managed for high yield produced 93% more biomass yield and an equivalent estimated NEY than previous estimates from human-made prairies that received low agricultural inputs.

Estimated average greenhouse gas (GHG) emissions from cellulosic ethanol derived from switchgrass were 94% lower than estimated GHG from gasoline. This is a baseline study that represents the genetic material and agronomic technology available for switchgrass production in 2000 and 2001, when the fields were planted. Improved genetics and agronomics may further enhance energy sustainability and biofuel yield of switchgrass.
Critique of Searchinger Scenario

<table>
<thead>
<tr>
<th></th>
<th>Searchinger</th>
<th>Real World</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Corn Starch Ethanol</strong></td>
<td>30 B gallons by 2015</td>
<td>➢ 15 B gallon cap in RFS</td>
</tr>
<tr>
<td><strong>Corn Yield</strong></td>
<td>Assumed constant</td>
<td>➢ Has increased 30% in past 10 years.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>➢ McKinsey project 15 B gallons can be produced with zero additional acres</td>
</tr>
<tr>
<td><strong>Cropping Practice</strong></td>
<td>Assumes conventional tillage</td>
<td>➢ Biotech corn varieties and collection of ag residues both support greater adoption of conservation tillage, which sequesters 2-3 times as much carbon in soil.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>➢ Conservation tillage rates for corn are steadily increasing.</td>
</tr>
<tr>
<td><strong>Ethanol Production</strong></td>
<td>Assumes no process improvements in future</td>
<td>➢ Efficiency and environmental profile improving rapidly</td>
</tr>
<tr>
<td></td>
<td></td>
<td>➢ New fractionation and “no cook” enzymes producing higher yield per bushel with lower energy inputs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>➢ New biorefineries moving to renewable sources of heat and power, e.g. methane, ag residues, lignin</td>
</tr>
<tr>
<td><strong>Feed + Fuel</strong></td>
<td>DDGs provide 1/3 as much animal feed as corn</td>
<td>➢ Recent research with latest fractionation indicates DDGs can replace ½ or more</td>
</tr>
</tbody>
</table>
### Critiques of Searchinger Scenario

<table>
<thead>
<tr>
<th>Dedicated Energy Crops</th>
<th>Searchinger</th>
<th>Real World</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grown on prime land</td>
<td></td>
<td>Many dedicated energy crops grow well in poorer soils, and can build soil and sequester carbon in the process.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Many perennial energy crops can be planted without tilling, and continuously sequester carbon even as above-ground biomass is harvested.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bioenergy crops can provide food/feed, fuels, and other high-value co-products from the same crop, making highest possible use of the land.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Indirect Land Use Impacts</th>
<th>Searchinger</th>
<th>Real World</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dramatically reduced corn exports</td>
<td>U.S. corn exports have not declined</td>
<td></td>
</tr>
<tr>
<td>Uses historical land use changes to predict future</td>
<td>legislation and more effective land management has reduced deforestation rates in Brazil and elsewhere</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Indirect land use changes are a function of land use policy. Sustainable biofuels production must go hand-in-hand with sustainable land use policy</td>
<td></td>
</tr>
</tbody>
</table>
Renewable Fuels Standard Requirements

Biotechnology is the Key

- Undifferentiated Advanced Biofuel
- Biomass-based Diesel
- Cellulosic Biofuel
- Renewable Biofuel

Year:
- 2008
- 2009
- 2010
- 2011
- 2012
- 2013
- 2014
- 2015
- 2016
- 2017
- 2018
- 2019
- 2020
- 2021
- 2022

Requirement (Billions of Gallons): 0 to 40

Biotech-Enabled

Biotech improved
Nils-Olof Nylund, Päivi Aakko-Saksa & Kai Sipilä

Status and outlook for biofuels, other alternative fuels and new vehicles

Bioenergy NoE
### Table 8.2. An example of scoring of various technology alternatives (suggestive, scoring by authors).

<table>
<thead>
<tr>
<th></th>
<th>Energy-security</th>
<th>Climate Change</th>
<th>Local pollution</th>
<th>Sustainable future</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy savings</td>
<td>+++</td>
<td>+++</td>
<td>+++</td>
<td>+++</td>
</tr>
<tr>
<td>Unconventional oil</td>
<td>++</td>
<td>-</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>Synfuels (GTL, CTL etc.)</td>
<td>++</td>
<td>0/-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>CNG in NGV</td>
<td>+</td>
<td>+/0</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Biofuels, 1st generation</td>
<td>+</td>
<td>+/0</td>
<td>+/0</td>
<td>+</td>
</tr>
<tr>
<td>Biofuels, 2nd generation</td>
<td>++</td>
<td>++</td>
<td>+</td>
<td>+++</td>
</tr>
<tr>
<td>Hybrids, HEV</td>
<td>+</td>
<td>++</td>
<td>++</td>
<td>+/+++</td>
</tr>
<tr>
<td>FC vehicles on ren. H₂ ³</td>
<td>+++</td>
<td>+++</td>
<td>+++</td>
<td>+++</td>
</tr>
</tbody>
</table>

+++ = very advantageous; — = very negative; 0 = neutral. ¹ long term option, not directly comparable with the other options. ²) biogas ³) plug-in hybrids
THANK YOU

Advanced Biofuels and Climate Change Information Center BLOG

http://biofuelsandclimate.wordpress.com/

NRDC Blog

http://switchboard.nrdc.org/blogs/ngreene/