Cellulosic Ethanol and Advanced Biofuels Overview

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The Biorefinery Concept

Biomass Feedstocks
- Trees
- Grasses
- Agricultural crops
- Residues
- Animal wastes
- Municipal solid waste

Conversion Processes
- Enzymatic fermentation
- Gas/liquid fermentation
- Acid hydrolysis/fermentation
- Gasification
- Combustion
- Co-firing
- Pyrolysis

Uses
- Fuels
  - Ethanol
  - Renewable diesel
- Power
  - Electricity
  - Heat
- Chemicals
  - Plastics
  - Solvents
  - Chemical intermediates
  - Phenolics
  - Adhesives
  - Furfural
  - Fatty acids
  - Acetic acid
  - Carbon black
  - Paints
  - Dyes, pigments, and ink
  - Detergents
- Food and Feed
U.S. National Commitment to Biofuels

Near-term – Cost Goal
“Cost-competitive cellulosic ethanol”
– Cost-competitive in the blend market by 2012

Longer-term – Volumetric Goal
EISA (Energy Independence & Security Act)
– 36 billion gallons renewable fuel by 2022
  • 21 billion gallons cellulosic + advanced biofuels

Renewable Fuel Standard (RFS) goals for biofuels penetration are based on specific GHG reductions from the fossil fuel it replaces.
• Biomass-based diesel 50% reduction
• Advanced biofuels 50% reduction
• Corn grain-based ethanol 20% reduction
• Cellulosic Biofuels 60% reduction
NREL Research Overview

NREL’s National Bioenergy Center Facilities

Thermochemical Conversion
  • Micro-reactors to pilot plants

Biochemical Conversion
  • Bench scale to ton/day

Genomics Laboratory
  • Tools for strain development

Biomass Characterization
  • Wet chemical and NIR

Spectroscopy Facilities
  • nmr, IR, LIBS, MBMS
Biomass Feedstock Overview

• Feedstock cost and logistics research for DOE is carried out at Idaho and Oak Ridge National Labs

• Key challenges:
  • Collection, processing and storage logistics
  • Consistent supply and quality
  • Quantity sufficient to justify large biofuels plants

• Biomass ultimately needs an industrial-class distribution system similar to corn
Cellulosic ethanol research at NREL

Biochemical Ethanol

Cellulosics → Chemical Pretreatment → Enzymatic Hydrolysis → Sugar → Fermentation → Ethanol

NREL core research includes:
- Increase pretreatment conversion
- Reduce enzyme cost
- Reduce commodity chemical usage

2008 State of Technology predicts $2.61/gal ($3.92/gal gas equiv.)

Thermochemical Mixed Alcohols

Cellulosics → Indirect Gasification → Syngas (CO+H₂) → Catalytic Synthesis → Mixed alcohols → Separation → Methanol, Ethanol, Propanol+

NREL core research includes:
- Increase tar reformer conversion
- Identify sulfur mitigation solution
- Improve alcohol synthesis catalyst performance

2008 State of Technology predicts $2.40/gal ($3.60/gal gas equiv.)
Cellulosic ethanol research at NREL

**Biochemical Ethanol**

- Cellulosics → Chemical Pretreatment → Enzymatic Hydrolysis → Sugar → Fermentation → Ethanol

- Conversion of biomass to sugar is reasonably well understood
- Remaining challenges are not specific to ethanol as a product
- What else can sugar be used for?

**Thermochemical Mixed Alcohols**

- Cellulosics → Indirect Gasification → Syngas (CO+H₂) → Catalytic Synthesis → Mixed Alcohols → Separation → Methanol, Ethanol, Propanol+

- Current catalyst selectivity is marginally acceptable
- Mixed alcohol separation adds cost and complexity
- What else can syngas be used for?
Future options for liquid fuel

RENEWABLES

**SUGAR**
- Corn Ethanol
- Cellulosic Ethanol
- Higher alcohols
- Renewable Hydrocarbons

**SYNGAS**
- Ethanol (catalytic)
- Ethanol (fermented)
- Fischer-Tropsch
- Methanol to gasoline

**FATS & OILS**
- Biodiesel
- Green diesel
- Pyrolysis oil
- Algae diesel (photosynth.)

Now

Near-term

Long-term
Advanced biofuels from sugar

Starch
- Sugarcane
- Cellulosics

Aqueous-Phase Reforming

Fermentation with engineered microbes
- LS9, Amyris
- Virent

Sugar

Fermentation

Ethanol

Dark Algae Oil
- Biodiesel
- Diesel
- Solazyme

Gasoline
- Diesel
- Jet

Benefits
- Infrastructure-compatible
- Highly controlled fuel properties

Challenges
- Feedstock availability
- Compatibility with cellulosic sugar
Advanced biofuels from synthesis gas

Dry Organic Material
- Cellulosics

Fischer-Tropsch Synthesis
- Gasoline
  - Diesel
  - Jet
  - Solena, Choren

Syngas gasification

Mixed Alcohol Synthesis
- Methanol
- Ethanol
- Propanol+

Fermentation
- Ethanol
  - Coskata, INEOS

Benefits
- Product versatility
- Proven technology

Challenges
- Biomass collection radius dictates smallish plant size
- Limited economy of scale
Advanced biofuels from fats and oils

Benefits
• Portability of oil intermediate
• Infrastructure compatibility

Challenges
• Land use change
• Pyrolysis process design
• Algae biology and culture

Dry Organic Material
Cellulosics
Envergent Tech.

Fats & Oils Natural or Waste

Dry Organic Material

Pyrolysis

Gasoline
Diesel
Jet

Hydrotreating & Upgrading

Gasoline

“Big Oil”
ConocoPhillips/Tyson
Neste, Petrobras, Shell/Choren

Biodiesel

Refinery

“Big Bang”
Livefuels
Greenfuels
PetroSun
Chevron
Boeing

Transesterification
<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Technology Status</th>
<th>Production Barriers</th>
<th>Market Barriers</th>
<th>Top Inhibitor</th>
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</thead>
<tbody>
<tr>
<td>Biochemical Ethanol</td>
<td>Pilot/Demo</td>
<td>Low</td>
<td>Medium</td>
<td>Feedstock availability</td>
</tr>
<tr>
<td>Thermo Mixed Alcohols</td>
<td>Pilot/Demo</td>
<td>Low</td>
<td>Medium</td>
<td>Feedstock availability</td>
</tr>
<tr>
<td>Green Diesel</td>
<td>Demo</td>
<td>Low</td>
<td>Low</td>
<td>Feedstock cost vs. oil</td>
</tr>
<tr>
<td>Fischer-Tropsch Diesel</td>
<td>Demo</td>
<td>Medium</td>
<td>High</td>
<td>Capital Investment</td>
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<tr>
<td>Methanol-to-Gasoline</td>
<td>Demo</td>
<td>Medium</td>
<td>High</td>
<td>Capital Investment</td>
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<tr>
<td>Renewable Hydrocarbons</td>
<td>Lab/Pilot</td>
<td>Medium</td>
<td>Medium</td>
<td>Feedstock availability</td>
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<tr>
<td>Pyrolysis oil</td>
<td>Lab</td>
<td>High</td>
<td>Low</td>
<td>Process Technology</td>
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<tr>
<td>Algal Diesel</td>
<td>Lab</td>
<td>Very High</td>
<td>Low</td>
<td>Process Technology</td>
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</tbody>
</table>

**Near Term**

**Long Term**
Summary and Conclusions

Biofuels are the only renewable option for liquid transportation fuels.

Ethanol and biodiesel are the best near-term options for deployment, but we must transition to cellulosic biomass.

NREL researchers are working to reduce ethanol conversion costs and provide public information on biofuel production economics.

Cellulosic ethanol is in the pilot stage with several demo plants planned.

Several options for advanced biofuels with better infrastructure compatibility are on the horizon.
Acknowledgements

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http://www.eere.energy.gov/biomass

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References:
Aqueous-Phase Reforming

Synthetic Biology for Fuels

Biomass Feedstocks