Biofuels and Feedstock Potential

by
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January 9, 2008
Outline

- Energy Consumption
- Drivers for Biofuels
- Biofuel Processes
- Feedstock Options
- Competition for Land Usage
Industrial Revolution & Energy Consumption

http://cdiac.esd.ornl.gov/trends/emis/em_cont.htm
Industrial Revolution & Temperature Change

Global Temperature Changes (1880-2000)

Source: U.S. National Climatic Data Center, 2001
Facts and Figures: World Energy Use

World Energy Use
400 Quads
Population ~ 6.5 billion
61.5 million Btu/capita
Facts & Figures: U.S. Energy Use

U.S. Energy Use
106 Quads
Population ~ 300 million
353 million Btu/capita
$10^{15} \text{ BTU} = 1 \text{ QUAD}$

- A burning Match: 1 BTU
- A stick of Dynamite: 2,000
- 100 hrs of TV: 28,000
- 1 gallon of Gasoline: 125,000
- Annual food for one Person: 3,500,000
- Heat St Louis House/Year: 90,000,000
- Apollo 17 to the Moon: 5,600,000,000
- Hiroshima Atomic Bomb: 80,000,000,000
- Oklahoma energy/year: 1,000,000,000,000,000
- US Energy consumption: 106,000,000,000,000,000
- World Energy consumption: 400,000,000,000,000,000
Peak Oil

- Defined as the point in time when production rate begins to decline. Usually coincides with ~ 50% of oil remaining in an oil field.
- American peak was reached in 1973.
- Global peak predicted in 2010-2020.
Daily Oil Production per Person-Day

Drivers for Renewable Fuels

- Global population growth
- Improved quality of life
- Fossil fuel availability
- Security/independence
- Climate change
- Energy policy
The President's Proposed Energy Policy

Jimmy Carter
Televised speech April 18, 1977

“Tonight I want to have an unpleasant talk with you about a problem unprecedented in our history. With the exception of preventing war, this is the greatest challenge our country will face during our lifetimes. The energy crisis has not yet overwhelmed us, but it will if we do not act quickly.

It is a problem we will not solve in the next few years, and it is likely to get progressively worse through the rest of this century…We simply must balance our demand for energy with our rapidly shrinking resources. By acting now, we can control our future instead of letting the future control us.”
U.S. Consumption of Renewable Energy

Total Renewable Energy Use 7.5 Quads

7.7% of U.S. Energy Consumption

- Hydroelectric 46.8%
- Wood and Waste 45%
- Geothermal 5.2%
- Solar & Wind 1.5%
- Ethanol Fuel 1.5%
Process for Converting Starch to Biochemicals

Current Process:
- Liquefaction:
  - Jet Cooker: 120 °C, 5-8 min.
- Saccharification:
  - Jet Cooker: 110 °C, 5-8 min.
  - 95 °C, 90 min.
- Purification:
- Ion Exchange Cabin:
  - 60 °C, 36-72 hrs.

Specialty Chemicals:
- Amino Acids
- MSG
- Sorbitol
- Citric
- Ascorbic
- Gluconic
- Lactic
- 1,3-Propanediol
- Antibiotics
- Enzymes
- Bio-pharmaceuticals

Biochemicals:
- Fructose
- Fuel Alcohol
Current Status - Ethanol

Information and images courtesy of BBI International
Ethanol Industry at a Glance

- Number of operating ethanol plants: >120
- Plants under construction or expansion: 86
- Announced plants: 300*
- 2006 production: 4.6 billion gallons
- Projected production capacity: 9.5 BG PY at end of 2007 (RFS Program mandate 7.5 BG by 2012)
- Size: Newer plants 100 MGPY
- Process: dry or wet
- Daily water usage – 1.5 million gallons
- Historic feedstock percentage:
  - Corn 97
  - Sorghum 2
  - Other 1
Coproducts from Corn Dry-grind Process

One bushel of Corn

Corn Dry-Grind Facility

2.7 gal of Ethanol

17 lbs of DDGS

Livestock Feed

Using Corn in Modified Corn Processing – David Johnston
Carbohydrate Bioconversion

<table>
<thead>
<tr>
<th>FEEDSTOCK</th>
<th>SUGAR (present)</th>
<th>STARCH (present)</th>
<th>CELLULOSIC (future)</th>
<th>TECHNOLOGY</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIOMASS (e.g., corn stover, switchgrass)</td>
<td></td>
<td></td>
<td></td>
<td>HYDROLYSIS: novel enzymes, acid, ammonia fiber extraction</td>
</tr>
<tr>
<td>STARCH (e.g., corn, wheat, rice)</td>
<td></td>
<td></td>
<td></td>
<td>ENZYMES: alpha-amyrase, glucoamylase</td>
</tr>
<tr>
<td>SUGAR (e.g., cane juice)</td>
<td></td>
<td></td>
<td>ETHANOL (blend, E85)</td>
<td>FERMENTATION: yeast</td>
</tr>
</tbody>
</table>
Cellulosic Ethanol

- More abundant, underutilized resource
  - Processing co-products
  - Crop residues
  - Dedicated energy crops
- Pretreatment process needed
- New enzyme systems
- 5-carbon sugars need to be fermented
Components of plant cell walls

- **Cellulose**
- **Lignin**
- **Hemicellulose** *(need special yeast to convert to ethanol)*
- **Extractives**
- **Ash**

Chapple, 2006; Ladisch, 1979
Pretreatment gives enzyme accessible substrate.
US Biomass inventory = 1.3 billion tons

- Corn stover: 19.9%
- Wheat straw: 6.1%
- Soy: 6.2%
- Crop residues: 7.6%
- Grains: 5.2%
- Manure: 4.1%
- Urban waste: 2.9%
- Forest: 12.8%
- Perennial crops: 35.2%
- Manure: 4.1%
- Corn stover: 19.9%
- Forest: 12.8%
- Soy: 6.2%
- Wheat straw: 6.1%
- Crop residues: 7.6%
- Grains: 5.2%
- Manure: 4.1%
- Urban waste: 2.9%
- Perennial crops: 35.2%

From: Billion ton Vision, DOE & USDA 2005

~ 3 tons/acre
## Net Energy Balance

<table>
<thead>
<tr>
<th>Product</th>
<th>Energy Out/Energy In</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline</td>
<td>0.81</td>
</tr>
<tr>
<td>Ethanol from grain</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td>(In-place technology)</td>
</tr>
<tr>
<td>Ethanol from grain</td>
<td>1.67</td>
</tr>
<tr>
<td></td>
<td>(Optimum technology)</td>
</tr>
<tr>
<td>Ethanol from cellulose</td>
<td>2.00</td>
</tr>
<tr>
<td></td>
<td>(Conservative estimates)</td>
</tr>
<tr>
<td>Diesel</td>
<td>0.83</td>
</tr>
<tr>
<td>Bio-diesel</td>
<td>3.2</td>
</tr>
</tbody>
</table>

Source: Congressional Research Service, RL32712, May 18, 2006
Cellulosic Ethanol
Energy Balance Estimates

- 5 years ago – 10-12 Ratio
- 2-3 years ago - 3-5 Ratio
- Current Estimate - 2.0

Why?
Improved recognition of costs associated with harvest, transportation & storage.
Harvest Issues

- Multiple passes thru field
- Soil compaction
- Organic matter retention
- Density of biomass limits transport
- Moisture content of biomass
Transportation Issues

- Density of Biomass
- Handling steps add costs
- Biomass form should be easily conveyed at plant location
Efficient transportation for bulky crops
Storage Issues

- **Storage Location**
  - In field
  - Satellite depots
  - Conversion plant

- **Change in composition**

- **Protection from elements**
Conclusions on Cellulosic Biomass Conversion

- Each time biomass is handled adds costs.
- New machinery will be required to manage costs.
- New process management paradigms needed.
- Six demonstration plants have been approved for federal funding.
Fast-pyrolysis Plant.
# Products of Fast Pyrolysis

<table>
<thead>
<tr>
<th>Product Yields (wt %, mf)</th>
<th>White Spruce</th>
<th>Poplar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>11.6</td>
<td>12.2</td>
</tr>
<tr>
<td>Char</td>
<td>12.2</td>
<td>7.7</td>
</tr>
<tr>
<td>Gas</td>
<td>7.8</td>
<td>10.8</td>
</tr>
<tr>
<td>Pyrolytic Liquids</td>
<td>66.5</td>
<td>65.7</td>
</tr>
</tbody>
</table>

**Gas Composition (wt %, mf)**

<table>
<thead>
<tr>
<th>Component</th>
<th>White Spruce</th>
<th>Poplar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
<td>0.02</td>
<td>--</td>
</tr>
<tr>
<td>CO</td>
<td>3.82</td>
<td>5.34</td>
</tr>
<tr>
<td>CO2</td>
<td>3.37</td>
<td>4.78</td>
</tr>
<tr>
<td>Hydrocarbons</td>
<td>0.62</td>
<td>0.69</td>
</tr>
</tbody>
</table>

**Pyrolytic Liquid Composition (wt %, mf)**

<table>
<thead>
<tr>
<th>Component</th>
<th>White Spruce</th>
<th>Poplar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saccharides</td>
<td>3.26</td>
<td>2.43</td>
</tr>
<tr>
<td>Anhydrosugars</td>
<td>6.45</td>
<td>6.77</td>
</tr>
<tr>
<td>Aldehydes</td>
<td>10.14</td>
<td>14.04</td>
</tr>
<tr>
<td>Furans</td>
<td>0.35</td>
<td>--</td>
</tr>
<tr>
<td>Ketones</td>
<td>1.24</td>
<td>1.4</td>
</tr>
<tr>
<td>Alcohols</td>
<td>2.0</td>
<td>1.17</td>
</tr>
<tr>
<td>Carboxylic Acids</td>
<td>11.01</td>
<td>8.52</td>
</tr>
<tr>
<td>Pyrolytic Lignin</td>
<td>20.6</td>
<td>16.2</td>
</tr>
<tr>
<td>Phenols, Furans, etc.</td>
<td>11.4</td>
<td>15.2</td>
</tr>
</tbody>
</table>

Biorenewable Resources, Robert C Brown
World Transport Vehicle Trends – Diesel

Direct Impact on Biofuels Production and Demand

- Global diesel volume has grown by 40% in 5 years
  - US market 2007 << 1%; 2017 ~ 12%
  - Eastern Europe 2007 15%; 2017 ~ 50%

- Conditions for further expansion of diesel look right
  - High energy prices (diesel 33% more efficient versus gasoline)
  - Diesel technology has come of age
  - Global focus on CO₂

- US will need diesel to hit fuel economy targets
One Driver: World Transport Vehicle Trends – Diesel

Direct Impact on Biofuels Production and Demand

- Global share of diesel market has increased 40% in the last 5 years

- Conditions for further expansion of diesel look right:
  - Global focus on CO₂ & Energy Security
    - High energy prices (diesel ~33% more efficient versus gasoline)
    - Diesel technology has improved (not dirty diesels anymore)

Where are the oilseed feedstocks going to come from to “fuel” this increase?
Renewable Oil Resources

- **Agricultural-based Feedstocks**
  - USA production per year (2006):
    - 26.2 billion lbs of major vegetable oils
    - 11.3 billion lbs of fats (animal & grease)
  - Global production per year (2006):
    - 246 billion lbs of major vegetable oils
    - 24 billion lbs of fats (animal & grease)
    - ~ 270 billion pounds (**135 million tons**)
# Drivers for Biofuels – Govt. Mandates

- **US** – Renewable Fuels Standard; 35 billion gallons by 2017
  (20% of projected total consumption)

- **EU** – 5.75% by 2010; 10% by 2020; 25% by 2030

- **China** – 36 B gal diesel used in 2006; 1.8 B gal biodiesel (from animal fat - low grade)
  Plans 90 B gal biodiesel in 2007

- China has said it aims to use 200,000 tons of biodiesel by 2010 and 2 million tons (604 billion gallons) by 2020.

**Why?** Energy Security, “Peak Oil” & Climate Change

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*How will these intersect with market forces, where exactly will the feedstocks come from, and at what price?*
## Acreage in Crops

(Millions of acres)

<table>
<thead>
<tr>
<th></th>
<th>5 yr. Ave.</th>
<th>07/08 USDA</th>
<th>08/09, Projected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>79.6</td>
<td>93.6</td>
<td>88.0</td>
</tr>
<tr>
<td>Soybeans</td>
<td>74.2</td>
<td>63.7</td>
<td>70.0</td>
</tr>
<tr>
<td>Hay</td>
<td>62.4</td>
<td>61.8</td>
<td>61.8</td>
</tr>
<tr>
<td>Wheat</td>
<td>59.5</td>
<td>60.4</td>
<td>62.2</td>
</tr>
<tr>
<td>Cotton</td>
<td>14.1</td>
<td>10.9</td>
<td>10.0</td>
</tr>
<tr>
<td>Grain Sorghum</td>
<td>6.1</td>
<td>7.7</td>
<td>7.4</td>
</tr>
<tr>
<td>Principle Crops</td>
<td>297.9</td>
<td>298.1</td>
<td>299.4</td>
</tr>
<tr>
<td>CRP</td>
<td>37.0</td>
<td>35.9</td>
<td>34.9</td>
</tr>
</tbody>
</table>

Total crop land in the United States – 441.6 million acres
U.S. Corn and Soybean Planted Acreage

Million Acres


Corn Soybeans
U.S Wheat Yields

Source: USDA & KSU
WASDE Report: 3.30.07

KSU Dept. of Ag Econ
www.agmanager.info
U.S. Soybean Yields

Source: USDA & KSU
WASDE Report: 3.30.07

KSU Dept. of Ag Econ
www.agmanager.info
U.S. Corn Yield

2004 Yield = 160 bu./ac
2005 Yield = 148 bu./ac
2006 Predicted Yield = 149 bu./ac

Source: USDA & KSU
KSU Dept. of Ag Econ
WASDE Report: 1.12.07
www.agmanager.info
World Corn Use Outpaces Production

- Consumption in 2006/07 is forecast to increase 3\% setting a new record.

- Production down from 2005/06.

- Stocks forecast to be second lowest in 34-years.
US Acreage for Biodiesel

- 74 million A of soybeans produced ~10 million tons of soy oil.
- This would convert to ~ 9 million tons of biodiesel = 2.7 B gal

- Current US consumption of diesel is 52 B gal.
- 2006 biodiesel production was 250 million gal.
- 10 million A = 360 million gal
Biofuel Acreage Demand

- Starch-based EtOH –
  35 million A = 15.1 B gal
- Cellulosic EtOH (dedicated energy crop);
  75 million A = 18 B gal
- Cellulosic EtOH (crop residues)
  100 million A = 8 B gal
- Biodiesel –
  10 million A = 360 million gal
  Import oil and animal = 640 mil gal

- Total of 120 million A = 42.1 B gal
  renewable fuels.
- 120/442 = 27% of crop land
Summary

- 140 B gal gasoline consumed/yr
- 52 B gal diesel consumed/yr
- Replace 30% of gasoline demand
- Replace 2 % of diesel demand
  - with crops from 27 % of crop land.
Conclusions

- Biobased resources will supplement energy requirements, but not replace petroleum.
- Competition for grain and acreage.
- Carryover is historically low; weather will become key driver for food prices.
- All renewable energy resources needed – no silver bullet.
- Reduction of energy demand will be required.
Thank You

?? QUESTIONS ??
## Energy Content of Fuels

<table>
<thead>
<tr>
<th>Fuel</th>
<th>MJ/liter</th>
<th>BTU/US gal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel</td>
<td>40.9</td>
<td>147,000</td>
</tr>
<tr>
<td>Gasoline</td>
<td>32</td>
<td>125,000</td>
</tr>
<tr>
<td>Butanol</td>
<td>29.2</td>
<td>104,949</td>
</tr>
<tr>
<td>E 10</td>
<td>28.06</td>
<td>120,900</td>
</tr>
<tr>
<td>LPG</td>
<td>22.2</td>
<td>95,475</td>
</tr>
<tr>
<td>Ethanol</td>
<td>19.59</td>
<td>84,400</td>
</tr>
<tr>
<td>Methanol</td>
<td>15</td>
<td>62,800</td>
</tr>
</tbody>
</table>
Additional Reading on Energy and Resource Consumption

  A great overview. As a technical and business writer, Roberts covers the range of topics that affect us as we approach and pass peak oil for the world.

- *Beyond Oil: The View from Hubbert’s Peak* – Kenneth Deffeyes (2005)
  A petroleum engineer explains Hubbert’s Peak for oil production and outlines a path forward with reduced oil availability.

  Simmons is an investment banker specializing in energy. He lives in Houston and has visited Saudi Arabia many times. His book explains why the aging Saudi oil fields are at or near peak.

  As a past Undersecretary of Energy, Romm speaks to the many overlooked deficiencies of hydrogen as a fuel. (It is an energy carrier, not a source.) He argues that hydrogen is very long term solution – at best.

- *Collapse: How Societies Choose to Fail or Succeed* - Jared Diamond (2005)
  Pulitzer Prize winning (Guns, Germs, and Steel) author Diamond, analyzes societies’ patterns of consumption with population expansion. Some transition into sustainable societies – some don’t. He draws parallels with today’s world society.

- *The Population Bomb* – Paul Erlich (1968)
  A modern-day Malthus with a warning on unlimited population growth. Human population reached its 1st billion in the world around 1803, soon after Malthus issued his warning; above 3.5 billion when Erlich’s book was written; above 6.5 billion now – and still ticking.

  An article urging scientists to speak up more on what they know about population, energy and limits to expansion. Albert A. Bartlett is emeritus professor of physics at the University of Colorado at Boulder. http://fire.pppl.gov/energy_population_pt_0704.pdf