The Race to the Future
Next Generation Biofuels

Wednesday, April 30, 2008
3:35 PM - 4:50 PM

Milken Institute
Global Conference 2008
Taking a trip from CA to NY: Comparing fuels

<table>
<thead>
<tr>
<th>Raw materials</th>
<th>Fuel required (gallon of gasoline or equivalents)</th>
<th>Fuel economy MPG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline</td>
<td>4.5 barrels crude oil</td>
<td>90.9</td>
</tr>
<tr>
<td>E85/ Ethanol</td>
<td>53 bushels of corn + half barrel crude</td>
<td>176</td>
</tr>
<tr>
<td>M85/ Methanol</td>
<td>18,190 cubic feet of natural gas + half barrel crude</td>
<td>214</td>
</tr>
<tr>
<td>B100 Biodiesel</td>
<td>80 gallons of used vegetable oil</td>
<td>68.2</td>
</tr>
<tr>
<td>Compressed natural gas</td>
<td>10650 cubic feet of natural gas</td>
<td>88</td>
</tr>
<tr>
<td>Electricity</td>
<td>1 ton of coal</td>
<td>16.4</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>16000 cubic feet of Hydrogen</td>
<td>73</td>
</tr>
<tr>
<td>Coal to liquid</td>
<td>1.1 tons of coal + 1485 gallons of water</td>
<td>92.8</td>
</tr>
</tbody>
</table>

Source: Popular Mechanics.
## Biofuel benefit comparison

<table>
<thead>
<tr>
<th>Biofuel Type</th>
<th>Land required to replace 5 percent U.S. gasoline consumption (MM acres)</th>
<th>Reduction in emissions (percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn ethanol</td>
<td>117</td>
<td>4 - 54</td>
</tr>
<tr>
<td>Sugarcane ethanol</td>
<td>41</td>
<td>56</td>
</tr>
<tr>
<td>Cellulosic ethanol</td>
<td>35-39</td>
<td>90.99</td>
</tr>
<tr>
<td>Soybean diesel</td>
<td>138</td>
<td>59.79</td>
</tr>
<tr>
<td>Cooking grease diesel</td>
<td>N/A</td>
<td>75.6</td>
</tr>
<tr>
<td>Algae diesel</td>
<td>.353*</td>
<td>Unknown</td>
</tr>
<tr>
<td>Coal to liquid</td>
<td>Dependent on coal mining</td>
<td>(4 - 118.5)</td>
</tr>
</tbody>
</table>

Sources: Sierra Club and National Council for Science and the Environment
Biodiesel production is more concentrated in Eastern U.S.
World biodiesel production potential, limited by feedstock

Million tons per year

Source: Emerging Markets Online
Projected greentech investment: Biofuel will grow

Source: Clean Edge 2008.
The unintended consequences of biofuels

“It is a crime against humanity to convert agricultural productive soil into soil which produces food stuff that will be burned into biofuel.”

-Jean Ziegler, U.N. Special Rapporteur

“The world’s most vulnerable who spend 60% of their income on food have been priced out of the food market”

-Josette Sheeran, head of the United Nations’ World Food Program

Source: UN News Centre
Corn prices per bushel
2004–Present

Source: Bloomberg
Panelists’ Slides
Frances Arnold
Professor of Chemical Engineering and Biochemistry
California Institute of Technology
Transportation accounts for ~ 28% of energy use (22% globally).
- Transportation accounts for 27% of global carbon emissions.
- Most transportation energy is from petroleum fuels.
- A lot of U.S. petroleum is imported (~60%).

Drivers for sustainable fuels
- Security of supply and energy diversification
- Climate change

U.S. Energy Flow, 2004 (Quads)

Source: Energy Information Administration.
Cellulosic feedstocks can be available on a large scale

- **Short term**
  - Wood, corn stover, rice straw, bagasse, corn fiber

- **Longer term**
  - High-yield dedicated energy crops (switchgrass, miscanthus, willow, etc.
    10-30 tons/acre)

1 year’s growth without replanting:

1.3 billion tons/year of cellulosic biomass could be made available

= 3.2 x 10^9 barrels of oil equivalent

(cf. US consumption of ~7 x 10^9 barrels oil/y)
Why is it hard to convert cellulosic biomass to fuel?

These produce usable sugars:

- ~45% Cellulose
- ~25% Hemicellulose
- ~25% Lignin
- ~5% Other

Cellulose microfibrils

Lignin

Source: Somerville et al. Science 306:2
Cellulose is “recalcitrant” because it is physically inaccessible.

Cellulose utilization requires additional processing steps ($$)

**FEEDSTOCK**  
- BIOMASS (e.g., corn stover, switchgrass)
- STARCH (e.g., corn, wheat, rice)
- SUGAR (e.g., cane juice)

**SUGAR** (present)  
**STARCH** (present)  
**CELLULOSIC** (future)

**TECHNOLOGY**
- HYDROLYSIS: novel enzymes, acid, ammonia fiber extraction
- ENZYMES: alpha-amylase, glucoamylase
- FERMENTATION: yeast

**ETHANOL** (blend, E85)
Multi-stage production makes for expensive processes and therefore expensive biofuels.
The greatest process simplification can be had by building the cellulose-to-fuel organism.
Complex molecular machines break down cellulose

White rot fungi figured it out; so did termites and many bacteria.
Cellulose degradation involves the simultaneous and synergistic action of multiple enzymes.
Cellulose degradation involves the simultaneous and synergistic action of multiple enzymes.
Ethanol

High water content
Low energy content

Butanol

Low water content
High energy content

<table>
<thead>
<tr>
<th></th>
<th>Gasoline</th>
<th>Ethanol</th>
<th>Butanol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy content</td>
<td>115 K</td>
<td>84 K</td>
<td>110 K</td>
</tr>
<tr>
<td>(BTU / gallon)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Butanol can be distributed in existing pipelines, storage tanks (*not* hygroscopic; non-corrosive)
- Butanol burns cleanly in unmodified gasoline engines
- Butanol can be blended with gasoline at any ratio
- Good intermediate to other fuels and chemicals
Combine Biology and Chemistry

Glucose (or any other sugar)

Any Renewable Resource

Butanols

Platform Intermediate Building Block

Fermentation

Other Alcohols

Gasoline Blend Stock

Direct Chemical Sales

Chemical synthesis

Diesel/Jet Blend Stocks

Chemicals

Plastics

Fibers

15
Caltech/UCLA synthetic biology challenge

Construct a microbe that converts cellulose to a better biofuel.
Hunt Ramsbottom
President and CEO
Rentech Inc.
Opportunities remain over next two decades

Sources: The Energy Independence and Security Act of 2007, EIA.
The Rentech process

Municipal Waste

Biomass

Pet Coke

Coal

Syngas

Gasification

Converted Hydrocarbons

Rentech Process

Upgrading

Diesel
Jet
Chemicals

CO₂ Capture Ready
Types of biomass

Urban
- Municipal solid waste
- Green waste
- Construction and demolition
- Sludge

Rural
- Agricultural waste
- Purpose grown
- Forestry waste
- Bagasse
Challenges of biomass

Source: Oak Ridge National Laboratory.
Product demonstration unit

Sand Creek, Colorado

- First fully integrated synthetic fuels demonstration facility
- Produces ultra-clean diesel, aviation fuels and naphtha
- Training center for operators
- Feedstock testing
  - Natural gas
  - Biomass
  - Petroleum coke
  - Coal
- Technology advancement
- First jet fuel production expected in June 2008
Ultra-clean fuel

- High performance
  - Higher cetane index improves engine performance

- Existing infrastructure
  - Today’s pipelines
  - Today’s engines

- Environmentally superior fuel
  - Significant emissions reduction
  - Exceeds global sulfur and aromatics requirements

- Storage stability
  - Long shelf life (≥ 8 years)

- Biodegradable
Weber Amaral, PhD
Brazilian Center for Biofuels
University of Sao Paulo – Brazil
Content

• Brazilian Center for Biofuels – Polo Nacional de Biocombustíveis
• Biofuels drivers
• Global problems – regional solutions
• Opportunities for the future and discussion
Brazilian Center for Biofuels background
The roles and functions of the Brazilian Center for Biofuels

“A Think Tank” at the University of Sao Paulo
Contributes to:

• Innovation and technology transfer: catalytic and network role
• Strategic and applied research
• ST and I supporting and influencing policies
• Awareness raising and capacity building
• Mitigation of GHGs and carbon projects
Our research agenda: Biofuels framework - *key drivers of supply and demand*

- System dynamics and their multiple interactions
Global problems, regional solutions

Brazilian structural factors leading to a competitive bionergy business

• At least two biofuels of global relevance: ethanol and biodiesel
• And one more underdeveloped potential: biogas
• Strong forestry sector
• Competitive production costs versus oil
• Potential for the development of co-products – oil chemistry and ethanol chemistry
• No IPRs frameworks for innovation until recently…
• Early stages of policy development – creation of global markets for biofuels: i.e., creation of bioenergy commission in Sao Paulo
• Long tradition in ethanol and sugar, although just two groups went public (IPO)
Biofuels markets

Of only 58 million ha of cultivated land, 6 million ha are used for sugarcane production

<table>
<thead>
<tr>
<th>Crop</th>
<th>Cultivated land (M Ha)</th>
<th>Production (M ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soybeans</td>
<td>21.5</td>
<td>49.5</td>
</tr>
<tr>
<td>Corn</td>
<td>12.3</td>
<td>41.8</td>
</tr>
<tr>
<td>Sugarcane</td>
<td>7.0</td>
<td>416.3</td>
</tr>
<tr>
<td>Bean</td>
<td>4.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Rice</td>
<td>3.7</td>
<td>13.3</td>
</tr>
<tr>
<td>Wheat</td>
<td>2.8</td>
<td>5.7</td>
</tr>
<tr>
<td>Coffee</td>
<td>2.4</td>
<td>2.5</td>
</tr>
<tr>
<td>Others</td>
<td>5.7</td>
<td>-</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>58.0</strong></td>
<td><strong>-</strong></td>
</tr>
</tbody>
</table>

Agricultural areas in Brazil and land use process

Brazilian Main Cropped Areas (MM Ha)

Source: MAPA; CONAB.
Energy factory

- 1/3 sugar
- 1/3 fibre
- 1/3 leaves

- 1ha = 9,000 l ethanol - 65 b of oil
- 6.5 MM ha = 490 MM barrels oil
- 6.5 MM ha CO2 uptake
- + 40% emissions from fossil fuels in Brazil.
The Brazilian sugarcane production map

The Brazilian sugarcane production map – concentration in the southern region of Brazil – 2.000 miles away from the Amazon

Location of mills and sugarcane production

Source: AGRINUAL/ IDEA.
Total production of sugarcane in Brazil increased significantly with the deployment of ethanol vehicles. The evolution of the Brazilian ethanol industry – M tons of processed sugarcane.

Source: Datagro.
Biofuels market *Sugarcane the most energy efficient raw material to produce ethanol*

Energy balance of ethanol production from different feedstocks

<table>
<thead>
<tr>
<th>Raw material</th>
<th>Production /ha (kg)</th>
<th>Quantity of Ethanol /ha</th>
<th>Energy Output/ Energy Input</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugarcane</td>
<td>85.000</td>
<td>7.080 liter</td>
<td>8.3</td>
</tr>
<tr>
<td>Corn</td>
<td>10.000</td>
<td>4.000 liter</td>
<td>1.3 - 1.8</td>
</tr>
</tbody>
</table>

Source: Petrobrás, Coehlo/Cenbio.
Agriculture technology and current genetic materials

Candidate genes and traits: the roles for GM sugarcane
- Water deficit
- Max. productivity potential – with irrigation
- Longer management cycles
- Sugar and fiber content & new allometric models

<table>
<thead>
<tr>
<th>Variety</th>
<th>Stage of cut</th>
<th>Yield (t/ha)</th>
<th>Trash* (t/ha)</th>
<th>Trash/stalk ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>SP79-1011</td>
<td>Plant cane</td>
<td>120</td>
<td>17.8</td>
<td>15%</td>
</tr>
<tr>
<td></td>
<td>2nd ratoon</td>
<td>92</td>
<td>15.0</td>
<td>16%</td>
</tr>
<tr>
<td></td>
<td>4th ratoon</td>
<td>84</td>
<td>13.7</td>
<td>16%</td>
</tr>
<tr>
<td>SP80-1842</td>
<td>Plant cane</td>
<td>136</td>
<td>14.6</td>
<td>11%</td>
</tr>
<tr>
<td></td>
<td>2nd ratoon</td>
<td>101</td>
<td>12.6</td>
<td>13%</td>
</tr>
<tr>
<td></td>
<td>4th ratoon</td>
<td>92</td>
<td>10.5</td>
<td>11%</td>
</tr>
<tr>
<td>RB72454</td>
<td>Plant cane</td>
<td>134</td>
<td>17.2</td>
<td>13%</td>
</tr>
<tr>
<td></td>
<td>2nd ratoon</td>
<td>100</td>
<td>14.9</td>
<td>15%</td>
</tr>
<tr>
<td></td>
<td>4th ratoon</td>
<td>78</td>
<td>13.6</td>
<td>17%</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>104</td>
<td>14.4</td>
<td>14%</td>
</tr>
</tbody>
</table>

* Dry matter
Biotechnology frameworks for supporting the full deployment of bioenergy and biofuels

Biotechnology is supporting the deployment of bioenergy and biofuels production in four main interconnected areas:

- Biomass production
- Biomass conversion technologies
- Environmental technologies
- Other associated process, i.e. co-products...

Just the production of biofuels at competitive costs is not sufficient now... beyond yield.

We need to understand biofuels externalities and energy balances.
Searching for solutions: a land use approach

- International and national demands: food & fuel
- Sustainable use of land and landscapes
- Added value of bioenergy materials
- Integration of agriculture/forests
- Diversifying the portfolio of farmer’s options
Optimizing the production and use of biomass: *The second generation of biofuels*

- Second generation of biofuels and biorefinaries: an example from the forestry sector and potential feedstocks in Brazil for the next 10 years
- Technologies for biomass conversion – using lignocellulosic material for ethanol production: multiple routes being considered
- Enzymatic; thermochemical process; gasification; etc.
Footprint and productivity
Sugarcane’s promise as a second-gen biofuels feedstock in Brazil

Unlike 1st generation ethanol, cellulosic ethanol yield does not vary significantly between feedstocks in terms of gallons / tonne. Therefore, the determining factor of end yield will be tonnes / hectare of biomass for each feedstock, giving sugarcane an advantage over other crops.
Main feedstocks for ethanol second generation in Brazil

<table>
<thead>
<tr>
<th>Sources</th>
<th>Area [mil ha]</th>
<th>Production [mil t/year]</th>
<th>Productivity [t/ha.year]</th>
<th>Properties (%)</th>
<th>Use potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leaves &amp; tops - cane</td>
<td>6,600</td>
<td>72,600</td>
<td>9 a 13</td>
<td>26</td>
<td>37</td>
</tr>
<tr>
<td>Bagasse - cane</td>
<td>6,600</td>
<td>72,600</td>
<td>9 a 13</td>
<td>20</td>
<td>41</td>
</tr>
<tr>
<td>Corn straw</td>
<td>11,549</td>
<td>64,029</td>
<td>5 a 8</td>
<td>15</td>
<td>30 a 45</td>
</tr>
<tr>
<td>Soy straw</td>
<td>22,933</td>
<td>80,747</td>
<td>3 a 4</td>
<td>15 a 25</td>
<td>30 a 40</td>
</tr>
<tr>
<td>Rice straw</td>
<td>3,919</td>
<td>2,937</td>
<td>4 a 6</td>
<td>23 a 35</td>
<td>36 a 40</td>
</tr>
<tr>
<td>Eucalyptus</td>
<td>4,000</td>
<td>94,600</td>
<td>22 a 24</td>
<td>20</td>
<td>45</td>
</tr>
<tr>
<td>Pinus</td>
<td>2,000</td>
<td>38,700</td>
<td>18 a 20</td>
<td>28</td>
<td>42</td>
</tr>
<tr>
<td>Grasses</td>
<td>115,000</td>
<td>460,000</td>
<td>3 a 5</td>
<td>10 a 30</td>
<td>25 a 40</td>
</tr>
</tbody>
</table>

Other sources - bamboo, sweet potato, cassava e sweet sorghum.

Sources: McMillan, 1994; Wood for Alcohol Fuels, 2002; Saad, 2005; IBGE; CONAB; SBS.
Improving technologies for biomass conversion

2nd generation of biofuels – No winners yet....
Policies and enabling environment

Sectoral policies affecting biofuels

• Energy
• Transport
• Agriculture
• Environment
• Conservation of biodiversity
• Economics
• etc
Projects on criteria and indicators - certification

Some issues to consider....

Criteria
- deforestation
- competition with food production
- biodiversity
- soil erosion
- fresh water
- nutrient leaching
- pollution from chemicals
- employment
- labour
- wages

Impact
- land availability
- yield
- costs
- crop management system
- quantity
- cost supply curve
Brazilian frameworks supporting ST and I in biofuels

Good examples from Pro-Alcool - ca. US$ 2 billion – 30 years

• Federal level
  – Ministry of Science & Technology
    • Agencies – CNPq and FINEP
    – Ministry of Education - CAPES

• State level – SP - the case of FAPESP

• Innovation law in BR – being implemented – facilitate interactions between academia and private sector
Biofuels Technology Park
Biofuels framework for innovation

Academia
- Universities
- Foundations
- Innovation agencies

Private
- Innovation centers
- R&D
- Advisors
- Partners’ networks
- Media
- Business partners
- Seminars

Government
- Agencies
- Incubators
- Tech parks

Brazil

Business pipeline

International partners
International exchange
Critical issues to be addressed

An agenda for collaboration

• Contribution of solid research to the process of making sound decisions: deploying the full potential of bioenergy sources and new technologies

• Awareness raising and capacity building – customer acceptance and potential benefits of biotechnology – making the bridge to the second generation of biofuels

• Enabling environment - necessary links among players: government – industry and academia – entrepreneurship and innovation -

• Quantitative and reliable information on biofuels benefits – from carbon and energy balances - supported by outlook studies – the need for a global assessment approach
Possible next steps – can not afford not to have...

- Concentration and concerted efforts: focus and scale
- Continuity: 30 years of investments worthwhile – the Brazil case
- Complementarity: bioenergy sources and expertise – need for an interdisciplinary approach
- Commitment: to make a change
- Coordination
Nathalie Hoffman
Managing Member and CEO
California Renewable Energies LLC
The U.S. greatest market opportunity
California

The land of ethanol opportunity

USA’s biggest ethanol market:
current demand ~ 1 BGY; less than 100 MGPY produced within state.

1st in U.S. in gasoline consumption – ethanol in U.S. is a gasoline blending component & therefore tracks gasoline consumption.

CA is major refining center for West Coast petroleum markets – ethanol is blended into gasoline near refining centers.

CA has mandatory gasoline blend rate of at least 5.6% ethanol, moving to 10% by 2012 when demand is projected to be 1.7 BGY (CA Energy Commission [“CEC”], 2007).

95% of CA’s ethanol travels to West Coast by train from the Midwest.

California ethanol blenders pay approx. $0.25 more per gallon of ethanol due to the cost of transporting it to CA by rail and other related logistical costs.
California:
Demand ~ 1 BGY
Local Production <75 MGY
Gap – Over 900 MGY

Source: Iowa State University.
## Comparison

*Cal Re’s cane vs. avg. U.S. corn ethanol*

<table>
<thead>
<tr>
<th></th>
<th><strong>Cal Re</strong></th>
<th><strong>Avg U.S.</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg. tons of cane/acre</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>No. of gallons of ETOH/ton of cane</td>
<td>24.7</td>
<td>2.8</td>
</tr>
<tr>
<td>Energy balance</td>
<td>11.6:1</td>
<td>1.35:1</td>
</tr>
<tr>
<td>Avg. yield of ethanol/acre</td>
<td>1,482 GPA</td>
<td>423 GPA</td>
</tr>
</tbody>
</table>
## Comparison

CA, Avg Florida, Louisiana and avg. state of Sao Paulo Brazil ETOH Data

<table>
<thead>
<tr>
<th></th>
<th>CA</th>
<th>FL</th>
<th>LA</th>
<th>Brazil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg. Tons of Cane/Acre</td>
<td>60</td>
<td>35.2</td>
<td>24.3</td>
<td>33.33</td>
</tr>
<tr>
<td>Avg. Sugar Content</td>
<td>15.79%</td>
<td>12.42%</td>
<td>11.97%</td>
<td>14.8%</td>
</tr>
<tr>
<td>Avg. Yield or Projected Yield of ETOH Acre</td>
<td>1482 GPA</td>
<td>695 GPA</td>
<td>465 GPA</td>
<td>750 GPA</td>
</tr>
</tbody>
</table>
### Comparison of Projected CA Yields and Avg Yields in State of Sao Paulo, Brazil

<table>
<thead>
<tr>
<th></th>
<th>CA</th>
<th>Avg SP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg. tons of cane/acre</td>
<td>60</td>
<td>33.33</td>
</tr>
<tr>
<td>Avg. sugar content</td>
<td>15%</td>
<td>14.8%</td>
</tr>
<tr>
<td>Avg. yield of ethanol/acre</td>
<td>1470 GPA</td>
<td>750 GPA</td>
</tr>
<tr>
<td>Energy balance</td>
<td>11.6:1</td>
<td>8.9</td>
</tr>
</tbody>
</table>
Why did ethanol prices go down last fall when the price of crude oil was so high, and why have they gone back up?
Ethanol from sugarcane grown in CA

Not a commodity like corn ethanol produced in the mid-West

- CA AB 32 - CA Global Warming Solutions Act of 2006
- CA Low Carbon Fuel Standard – transportation fuel
- CA Renewable Portfolio Std – renewable electricity
- CA Bioenergy Action Plan
- Gov. Schwarzenegger’s Exec Order S-06-06 – instate production of biofuel feedstocks
- CA State Alternative Fuels Plan
- CA AB 118 – grants, loans, loan guarantees, etc. for alternative fuels projects; preferences for CA projects
- US Renewable Fuel Standard – EPAct ’05 definition of “cellulosic biomass ethanol” includes sugar cane ethanol
- Increased Fed RFS under new ES&IA (2007), including carve-out for sugar cane ethanol as an “advanced biofuel”
Renewable products from sugarcane

- Ethanol and co-products, such as CO2 and potassium-rich fertilizer
- Electricity
- Building materials
- Paper products
- Industrial chemicals
- Plastics
~ 10% of total cultivated land

~ 1% of total land available for agriculture

Sources: Professor Suani Coelho, Brazilian Reference Center on Biomass
The Amazon is not a good place to grow sugarcane

- It rains too much – in order to harvest sugarcane to make ethanol, you need a dry season.
- A high yield of ethanol depends on two factors: the number of tons/acre of cane plus the sugar content. To accumulate sugar content, the cane plant needs some cold weather to “shock” the plant. It doesn’t get cold enough in the Rain Forest to “shock” the plant.

Therefore …
Sugarcane plantations in Brazil

Not in Amazonia!

Not in Atlantic Rain forest!

Not in Pantanal!

Sources: Professor Suani Coelho, Brazilian Reference Center on Biomass
Where does sugarcane grow in Brazil if not in the Amazon?

• Approx. 65% grows in the state of Sao Paulo, more than 1000 miles away from the rainforest.

• Another approx. 12.5% grows in the poor and dry North/Northeast of the country.

• Expansion in the growth of sugar cane is moving westward into the low population areas of Brazil’s wild west.

• Brazil, bigger than the continental U.S. with a little more than ½ of the population, has 216 MM acres of non-rain forest arable land available to plant sugarcane. There is no food vs fuel problem.
The lack of competition for land with food

Harvested Area in Brazil

Source: Brazilian Statistics Bureau, several years
Productivity curves for ethanol and sugarcane in Brazil

Sources: Rodrigues, Unicamp 2005.
Ethanol energy balance
(now increased in new, soon to be published work by Dr. Macedo)

<table>
<thead>
<tr>
<th>Activity</th>
<th>Energy consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Scenario 1 (kcal/TC)</td>
</tr>
<tr>
<td>Sugar cane production (total)</td>
<td>48,208</td>
</tr>
<tr>
<td>Agricultural operations</td>
<td>9,097</td>
</tr>
<tr>
<td>Transportation</td>
<td>10,261</td>
</tr>
<tr>
<td>Fertilizers</td>
<td>15,890</td>
</tr>
<tr>
<td>Lime, herbicides, pesticides etc.</td>
<td>4,586</td>
</tr>
<tr>
<td>Seeds</td>
<td>1,404</td>
</tr>
<tr>
<td>Equipment</td>
<td>6,970</td>
</tr>
<tr>
<td>Ethanol production (total)</td>
<td>11,800</td>
</tr>
<tr>
<td>Electricity</td>
<td>0</td>
</tr>
<tr>
<td>Chemicals, lubricants</td>
<td>1,520</td>
</tr>
<tr>
<td>Buildings</td>
<td>2,860</td>
</tr>
<tr>
<td>Equipment</td>
<td>7,420</td>
</tr>
<tr>
<td><strong>External energy flows</strong></td>
<td></td>
</tr>
<tr>
<td>Agriculture</td>
<td>48,208</td>
</tr>
<tr>
<td>Factory</td>
<td>11,800</td>
</tr>
<tr>
<td>Ethanol produced</td>
<td></td>
</tr>
<tr>
<td>Surplus bagasse</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>60,008</strong></td>
</tr>
<tr>
<td><strong>Output/input</strong></td>
<td><strong>8.3</strong></td>
</tr>
</tbody>
</table>

Source: Macedo, I et alli, 2004
Biodiesel, biomass and sugarcane

• Separate analysis, biodiesel from soybeans increases GHGs by 158% over 30 years

• Biomass grown on soybean fields
  – 70% reduction without land conversion (GREET)
  – 50% increase in emissions with land conversion

• Brazilian sugarcane
  – 85% reduction without land conversion (Macedo et al.)
  – 4 year payback period if conversion from grassland, and 45 years if converted from rain forest directly or indirectly
  – But it’s worth exploring solutions
Criticisms

- Misrepresentations of study
  - Level of ethanol
  - Yields
  - Export predictions
  - Pristine ecosystems (worst case)

- What about oil land use?

- Export reactions to existing ethanol

- Confusing baseline with incremental effect of biofuels
  - Improved forest protection
  - Even bigger yields
Where should we focus?

- Biofuels from waste products
  - biggest cheapest source
- Use of “marginal,” unproductive lands (maybe)
- Algae?
- Fall harvests from reserve lands
Net Return (profit) per Bushel and per Gallon
(2005 to present)

Percent Return on Equity
(annualized basis, 2005 to present)
Comparison: Cal Re’s cane vs. average U.S. corn ethanol

<table>
<thead>
<tr>
<th></th>
<th>Cal Re</th>
<th>Avg US</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg. Tons of Cane/Acre</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>No. of gallons of ETOH/ton of cane</td>
<td>24.7</td>
<td></td>
</tr>
<tr>
<td>Energy Balance</td>
<td>11.6:1</td>
<td>1.35:1</td>
</tr>
<tr>
<td>Avg. Yield of ethanol/Acre</td>
<td>1,482 GPA</td>
<td>423 GPA</td>
</tr>
</tbody>
</table>

Comparison of projected CA, Avg Florida, Louisiana and Avg State of Sao Paulo, Brazil ETOH Data

<table>
<thead>
<tr>
<th></th>
<th>CA</th>
<th>FL</th>
<th>LA</th>
<th>Brazil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg. Tons of Cane/Acre</td>
<td>60</td>
<td>35.2</td>
<td>24.3</td>
<td>37</td>
</tr>
<tr>
<td>Avg. Sugar Content</td>
<td>15.79%</td>
<td>12.42%</td>
<td>11.97%</td>
<td>14.8%</td>
</tr>
<tr>
<td>Avg. Yield or Projected Yield of GPA</td>
<td>1482 GPA</td>
<td>695 GPA</td>
<td>465 GPA</td>
<td>750 GPA</td>
</tr>
</tbody>
</table>

*Source: Macedo et al, Biomass & Bioenergy (2007)*
Comparison of projected CA yields and avg yields in state of Sao Paulo, Brazil

<table>
<thead>
<tr>
<th></th>
<th>CA</th>
<th>Avg SP</th>
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<tr>
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<td>750 GPA</td>
</tr>
<tr>
<td>Energy Balance</td>
<td>11.6:1*</td>
<td>9.3*</td>
</tr>
</tbody>
</table>

Use of Cropland for Biofuels Increases Greenhouse Gas Emissions Through Land Use Change

Tim Searchinger, Ralph Heimlich, R.A. Houghton, Fenxia Dong, Amani Elobeid, Jacinto Fabiosa, Simla Tokgoz, Dermot Hayes, Tun-Hsiang Yu (tsearchi@princeton.edu) – find papers at www.gmfus.org
Land conversion means all foregone storage and ongoing sequestration

Emission from Land Use Change
- Release of carbon stored in plants and soil when forest and grassland is plowed up directly or indirectly
- Foregone ongoing sequestration
- Foregone annual, ongoing carbon sequestration on former grassland and forest that was converted or on croplands that would revert to grassland or forest absent
Indirect effect occurs through price

- Morton et al, Cropland Expansion Changes Deforestation Dynamics in the southern Brazilian Amazon, PNAS 103(39):14637-41 – showing rate of deforestation increases with price
- Crop expansion also pushes grazers into converting forest
Using cropland to produce biofuels will cause large increases in greenhouse gases from land use change

- ▶ Most diverted grain will be replaced (even after crediting biofuel feed by-products)
- ▶ Breaking out cropland is cost-effective way of meeting new demand
- ▶ Losses on any forest or grassland converted to cropland are high
- ▶ compared to annual gains per hectare of biofuel:
  - Corn-based ethanol (2015)
  - Switchgrass (2015) versus
  - Forest conversion
  - Grassland conversion

- 1.8 tonnes/hectare/year gain (GHG Co2 eqv.) (by comparison with using gasoline)
- 8.6 tonnes/hectare/year gain
- 604-1146 tonnes/hectare loss + ongoing sequestration
- 75 – 305 tonnes/hectare loss (+ displaced grass feed)
Biodiesel, biomass & sugarcane

• Corn ethanol nearly doubles emissions from driving over 30 years
• Corn ethanol pays back carbon debt after 167 years

Sensitivity:
• If 20% of diverted grain replaced by increase in yields  
  – 133 year payback
• If ethanol emissions savings, absent land conversion, double  
  -- 83 year payback
• If per acre land emissions from conversion were half of our  
  estimate – 83 year payback
• If all true – 34 year payback
• Obvious biodiversity impacts, water impacts
Biodiesel, biomass and sugarcane

Separate analysis, biodiesel from soybeans increases GHGs by 158% over 30 years

Biomass grown on soybean fields
• 70% reduction without land conversion (GREET)
• 50% increase in emissions with with land conversion

Brazilian sugarcane
• 85% reduction without land conversion (Macedo et al.)
• 4 year payback period if conversion from grassland, and 45 years if converted from rainforest forest directly or indirectly
• But it’s worth exploring solutions