Bioeconomics of Biofuels: Grassland Restoration and Renewable Energy

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The Energy Problem

• How will society meet growing energy demands in a sustainable manner?
• Fossil-fuels currently supply ~80% of world energy demand.
The Problems of Addiction to Fossil-Fuels

• Climate change: carbon emissions from fossil-fuels
• Other environmental impacts (SOx, NOx, particulates…)
• Energy security: large fraction of oil comes from the Middle East
• Supply availability: finite stock
  – US has had declining oil production since the 1970s
• Even with finite supplies, we have more than enough coal to do serious long-lasting environmental damage
The Energy Problem

• “Sustainable carbon-neutral energy is the most important scientific challenge we face today”
  – Steven Chu, Director Lawrence Berkeley National Laboratory (9 Feb 2007 *Science*)
Desperately Seeking Alternatives

• To be an attractive alternative, an energy source must be:
  • Producible in large quantities
  • Environmentally benign
  • Cost-competitive
Are Biofuels the Answer?...
Biofuels as an Alternative

• Biofuels are not THE answer to sustainable energy, but biofuels may be part of the answer

• Biofuels may offer advantages over fossil fuels, but the magnitude of these advantages depends on how a biofuel crop is grown and converted into a usable fuel
Analysis of Alternative Biofuels

• “First generation” biofuels: food-based biofuels that are currently commercially available:
  – Corn-grain ethanol
  – Soy Biodiesel
• “Second generation” biofuels: cellulosic biofuels of the future
  – Diverse prairie biomass
Analysis of First Generation Biofuels


• Comparison of
  – Corn-grain ethanol v. gasoline
  – Soy biodiesel v. diesel

• Criterion:
  – Energy supply
  – Environmental impact
  – Cost
Historic U.S. Ethanol Production

Source: Data from Renewable Fuels Association. 2006 figure is U.S. ethanol production capacity as of November 30, 2006.
Current FAPRI Projections
Ethanol vs. Corn Exports

Source: Data from FAPRI July 2006 Baseline Update for U.S. Agricultural Markets
Are Biofuels Net Energy Sources?

• Controversy over whether biofuels are a net energy source or a sink
• Net Energy Balance (NEB): energy output – energy inputs
• Positive NEB means that biofuel is a source: more useful energy output than the energy input to create it
Are Biofuels Net Energy Sources?

• Lifecycle assessment of all energy inputs
  – Energy to grow crops (fertilizer, farm equipment…)
  – Energy to convert crops to biofuel
  – Energy for transportation (crop to production facility, and fuel from production facility to end user)

• Assessment of all energy outputs
  – Energy content of the fuel itself
  – Co-products
Net Energy Balance for Corn Grain Ethanol and Soy Biodiesel

<table>
<thead>
<tr>
<th></th>
<th>Corn grain ethanol</th>
<th>Soybean biodiesel</th>
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<tbody>
<tr>
<td>NEB</td>
<td>0.24</td>
<td>0.81</td>
</tr>
<tr>
<td>NEB Ratio</td>
<td>1.25</td>
<td>1.93</td>
</tr>
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</table>
How Much Do They Supply?

• Corn grain ethanol (2005):
  – 14.3% of the US corn harvest was used to produce $1.48 \times 10^{10}$ L of ethanol annually
  – Energetically equivalent to 1.72% of US gasoline use

• Soy biodiesel (2005)
  – 1.5% of the US soybean harvest produced $2.56 \times 10^8$ L of biodiesel annually
  – 0.09% of US diesel use
But How Much Could They Supply?

• Devoting all US corn and soybean production to biodiesel and ethanol would generate:
  – 12% of US gasoline consumption
  –  6% of US diesel consumption

• In terms of net energy gain:
  – 2.4% of US gasoline consumption
  – 2.9% of US diesel consumption
Food vs. Fuel: Impact on Corn Prices

[Graph showing the average US corn price from 2003 to 2006. The price trends are indicated with a line graph.]
Ethanol Demand and Corn Prices

• Large increase in demand for corn for ethanol production
  – Production capacity over 5 billion gallons
  – Projected to increase to over 9 billion gallons with current plants under construction

• Corn prices in January 2007 topped $4/bushel

• Price has doubled since early 2006
Environmental Consequences

• At first glance, we might think that biofuels are environmentally friendly
• Is this correct?
• It depends on how biofuels are produced
Environmental Consequences per Unit Energy

(a) Application per NEB (g/MJ)

(b) Application per NEB (g/MJ)

- Fertilizer
  - N: 7.0
  - P: 2.6

- Pesticide
  - Other Glyphosate: 0.10
  - Metolachlor: 0.06
  - Acetochlor: 0.04
  - Atrazine: 0.01
  - Other: 0.001

- Corn grain ethanol
- Soybean biodiesel
Greenhouse Gas Emissions per Unit Energy

- Corn grain ethanol: 84.9 g/MJ
- Gasoline: 96.9 g/MJ
- Soybean biodiesel: 49.0 g/MJ
- Diesel: 82.3 g/MJ
Environmental Consequences per Unit Energy

• All else equal, an NEB > 1 should mean lower CO$_2$ emissions (replace fossil fuel use)

• But: increased N$_2$O and methane emissions from crop production

• Lifecycle greenhouse gas emissions
  – Ethanol: 88% of gasoline
  – Soy biodiesel: 59% of diesel
Are Biofuels Cost Competitive?

• In 2005, neither biofuel was cost-competitive with petroleum – but as petroleum prices increased the gap closed
  • Ethanol:
    – Estimated ethanol production cost in 2005 was $0.46 per gasoline energy equivalent L
    – Wholesale gasoline prices averaged $0.44/L in 2005
  • Soy biodiesel
    – Estimated soybean biodiesel production cost in 2005 was $0.55 per diesel EEL,
    – Diesel wholesale prices averaged $0.46/L in 2005
• Recent price effects unfavorable for biofuels:
  – Lower fossil-fuel prices
  – Higher corn prices
Are Biofuels Profitable?

• Though not cost competitive, biofuels can be profitable given subsidies (and are profitable given subsidies and current high oil prices)
• Federal government provides subsidies of
  – $0.20 per EEL for ethanol
  – $0.29 per EEL for biodiesel
• Demand, especially for ethanol, generated by laws or regulations mandating blending of a biofuel with petroleum
• Ethanol and biodiesel producers also benefit from federal corn and soybean subsidies
  – Corn prices are approximately half of ethanol production’s operating costs
Summary

- Corn grain ethanol and soy biodiesel can make up only a small portion of fuel supply
- Subsidize environmentally friendly biofuels
  - Subsidy for corn grain ethanol does not appear justified
  - Subsidy for soy biodiesel may be justified
- Should look to other sources
Second Generation Biofuels: Cellulosic Feedstock…

Switchgrass  Wheat Straw  Hybrid Poplar  Corn Stalks

Polasky LTER Mini-symposium
3/8/07
Analysis of a Second Generation Biofuel: Energy from Prairie Grasses

Cedar Creek Biodiversity Experiment...
More Diverse Plots Yield More Biomass Energy
More Diverse Plots Become Increasingly Productive
Energy Input and Output: First and Second Generation Biofuels

![Chart showing energy input and output for biofuels]

- **Current biofuels**
  - Energy input or output (GJ ha\(^{-1}\))
  - Delivered energy outputs:
    - Biofuel
    - Coproducts
    - Electricity
  - Fossil energy inputs:
    - Farm
    - Conversion

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<tr>
<th>NEB (Output - Input)</th>
<th>NEB ratio (Output / Input)</th>
<th>Corn grain ethanol</th>
<th>Soybean biodiesel</th>
<th>Biomass electricity</th>
<th>Biomass ethanol</th>
<th>Biomass synfuel</th>
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<tr>
<td>18.9</td>
<td>1.25</td>
<td>14.4</td>
<td>1.93</td>
<td>5.51</td>
<td>5.44</td>
<td>8.09</td>
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*Polasky LTER mini-symposium*

*3/8/07*
Net Energy Per Hectare

- Food-based biofuels on fertile soils
- Low-input high-diversity prairie bioenergy on degraded soil

Net energy gain (GJ ha$^{-1}$)

0 5 10 15 20 25 30

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2/3 of the Prairie is Below Ground
Carbon Storage

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Greenhouse Gas Reduction From Biomass Energy to Replace Fossil-Fuel Consumption

![Graph showing greenhouse gas reduction in kg CO₂ eq. ha⁻¹ for different energy sources: corn grain ethanol, soybean biodiesel, biomass electricity, biomass ethanol, and biomass synfuel.](image)
# Nutrient Input

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<tr>
<th>kg ha(^{-1}) yr(^{-1})</th>
<th>Corn</th>
<th>LIHD Prairie</th>
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<tbody>
<tr>
<td>N</td>
<td>148</td>
<td>0</td>
</tr>
<tr>
<td>P</td>
<td>23</td>
<td>4</td>
</tr>
<tr>
<td>K</td>
<td>50</td>
<td>6</td>
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</table>
Comparing Current and Future Biofuels

![Bar chart showing fertilizers and pesticides for different biofuels.]
Summary: Benefits of Low-Input High-Diversity Grassland Biomass

• Producible on degraded agricultural lands
  – Reduce competition with food production
  – Can be done in a manner consistent with environmental values (cropping in the fall after bird fledging…)

• Carbon-negative fuel when produced on degraded lands

• Low inputs – low export of nutrients

• More net energy gain per acre than food based-biofuels
Summary: Open Questions

• Economics: is it cost-competitive?
• Technology: turning lignocellulosic biomass into hydrocarbon fuel presents significant challenges
  – But electricity production can be accomplished with existing technology
Conclusions...

• Current food- and feed-based biofuels can meet but a small portion of transportation energy needs and do so at great environmental cost

• Next generation lignocellulosic biofuels from waste and prairie grasses have distinct advantages over current biofuels
Final Thought

• “Agriculturalists are the *de facto* managers of the most productive lands on Earth. Sustainable agriculture will require that society appropriately rewards ranchers, farmers and other agriculturalists for the production of both food and ecosystem services.” (Tilman et al. Nature 2003)
Acknowledgements

• Initiative for Renewable Energy and the Environment (IREE)
• National Science Foundation
• Howard Hughes Medical Institute
• Bush Foundation
• David Tilman, Jason Hill, Erik Nelson, Doug Tiffany, Clarence Lehman
• Kyla Bauer, Diego Bonta, John Carmody, Leah Dornfeld, Vernon Eidman, Joe Fargione, Darrell Gerber, Kshama Harpankar, Frank Kulacki, Jennifer Kuzma, Eric Larson, Dan Petrolia, Sangwon Suh, Robert Williams