Biomass Energy: the Climate-Protective Domain

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The Climate-Protective Domain

If done right, using biomass for energy could:
• Reduce greenhouse gas emissions (GHGs)
• Reduce dependence on foreign oil
• Enhance rural economies and, in some cases, food security
• Mobilize investment in agricultural technologies and infrastructure

BUT, there are risks that bio-energy could:
• Compete with food, driving up food prices and food insecurity
• Indirectly cause land clearing and large GHG emissions
• Divert attention from cheaper or more effective climate mitigation measures

So how do we identify the subset of bio-energy options that would truly help to slow climate change?
Figure 5.2: Vehicle ownership as a function of per capita income
Note: plotted years vary by country depending on data availability.
Figure 5.3: Projection of transport energy consumption by region and mode

Source: WBCSD, 2004a.

IPCC, WG3, 2007
Figure 3.7  Coarse grains: food and non-food use

Mainly for livestock
The Climate-Protective Domain

The climate effects of bio-energy will depend on:

1. What resources go into biomass production
2. What feedstocks are produced
3. If and how these feedstocks are processed into other forms of energy
4. What the end uses of this energy are
5. How effectively the process can be scaled

Modified from FAO 2008
Resources
Land, Water, Fertilizer, etc.

Feedstocks
Maize, Sugarcane, Miscanthus, etc.

Bioenergy
Ethanol, Biodiesel, Biogas, Fuelwood, etc.

End Use
Transportation, Heating, etc.

e.g.,

US Cropland → Maize → Ethanol → Internal Combustion Vehicles
A Tough Year for Corn Ethanol

Sources: Corn price, USDA; oil price, DOE/EIA, refiner composite crude oil acquisition price.

**Table 6: Crude, Gasoline, and Corn Price Correlations**

<table>
<thead>
<tr>
<th>Period</th>
<th>Correlation type</th>
<th>Correlation</th>
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</thead>
<tbody>
<tr>
<td>1988-2005</td>
<td>Crude - gasoline</td>
<td>0.95</td>
</tr>
<tr>
<td></td>
<td>Crude – corn</td>
<td>-0.26</td>
</tr>
<tr>
<td>2006-2008</td>
<td>Crude - gasoline</td>
<td>0.92</td>
</tr>
<tr>
<td></td>
<td>Crude – corn</td>
<td>0.80</td>
</tr>
</tbody>
</table>

Abbott et al. 2009, Farm Foundation Report
Higher food prices are likely bad for climate
Higher food prices are likely bad for climate

Figure 2. (a) Pre-deforestation biomass (Mg C ha$^{-1}$) in the Brazilian Amazon. Federal and indigenous reserves are in gray. The color code for Figure 2a is the orange-to-green scheme shown in Figure 2b. (b) Histograms of biomass previously cleared (top) in 2001–2005, (middle) in 2006–2007, and (bottom) biomass in remaining forests in 2007. Y-axis represents the frequency of 100 km$^2$ areas.
Resources
Land, Water, Fertilizer, etc.

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End Use
Transportation, Heating, etc.

- e.g.,
  - US Cropland → Maize → Ethanol → Internal Combustion Vehicles
  - Abandoned cropland → Perennial Grass (e.g. Miscanthus) → Ethanol → Internal Combustion Vehicles

“Second Generation”
Total potential: 
~1 B ton C 
or 
~8% of global energy use

FIGURE 2. Biomass production potential on abandoned agriculture lands. (A) Natural above-ground production of biomass on all lands determined from the CASA model, assuming 50% of the biomass is above-ground and the ratio (by mass) of biomass to carbon is 2.2. (B) Potential above-ground production of biomass on abandoned agriculture lands at the country level. (C) Ratio of the energy content of the biomass on abandoned agriculture lands relative to the current primary energy demand at the country level. The energy content of biomass is assumed to be 20 kJ g⁻¹.

Campbell, Lobell, Field, Env. Science & Tech., 2008
Resources
Land, Water, Fertilizer, etc.

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Bioenergy
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End Use
Transportation, Heating, etc.

- **US Cropland** → Maize → Ethanol → Internal Combustion Vehicles
- Abandoned cropland → Perennial Grass (e.g. Miscanthus) → Ethanol → Internal Combustion Vehicles
- Or
- Abandoned cropland → Perennial Grass (e.g. Miscanthus) → Electricity → Electric Vehicles

- e.g.,

**Resources**
Land, Water, Fertilizer, etc.

**Feedstocks**
Maize, Sugarcane, Miscanthus, etc.

**Bioenergy**
Ethanol, Biodiesel, Biogas, Fuelwood, etc.

**End Use**
Transportation, Heating, etc.
Ethanol vs. Electricity

The Land
Only a limited area of cropland is available to grow biofuel crops without causing an increase in food prices or deforestation.

The Choice
The plant biomass grown on this limited land could be used for transportation via different energy pathways such as ethanol and electricity.
Ethanol vs. Electricity

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The Choice
The plant biomass grown on this limited land could be used for transportation via different energy pathways such as ethanol and electricity.

Biomass into ethanol
- Ethanol refineries include pre-treatment, biological treatment and purification steps.
- Ethanol could be distributed by truck or pipeline.
- Ethanol is pumped at fuel stations.
- Energy is used to produce internal combustion vehicles.

Biomass into electricity
- Biomass is burned to make steam.
- Steam turns a turbine.
- The turbine turns a generator.
- Electricity is transmitted through the grid.
- Batteries are charged at fuel stations, homes, and businesses.
Ethanol vs. Electricity

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Only a limited area of cropland is available to grow biofuel crops without causing an increase in food prices or deforestation.

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The plant biomass grown on this limited land could be used for transportation via different energy pathways such as ethanol and electricity.

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Biomass is burned to make steam. Steam turns a turbine. The turbine turns a generator.

Energy is used to produce internal combustion vehicles.

Ethanol could be distributed by truck or pipeline.

Ethanol is pumped at fuel stations.

The Result
Using the biomass to produce electricity for electric vehicles would produce 11% more transportation than using the same amount of biomass to produce next-generation ethanol for internal combustion engine vehicles. The electricity option also has a greater potential for reducing CO₂ emissions than ethanol.

The miles that could be driven using the annual harvest from one acre of cropland vary for different factors such as crop yield and vehicle class. The example shown here is for a switchgrass crop and a small SUV.

8,000 miles per acre

15,000 miles per acre

Credit: McClure and Campbell / UC Merced
Based on: Campbell et al. Science 2009
The result:
Bioelectricity vs Bioethanol

- 81% more km Ha\(^{-1}\)
- 108% more GHG offsets
Summary

• Productive land is an increasingly scarce resource
• Focusing on feedstocks and conversion technologies risks missing the big opportunities
• Significant technology hurdles exist for both 2nd generation ethanol and electric vehicles
• Bio-electricity links well to carbon capture and sequestration
Thank you.
Haszeldine, Science, 2009
<table>
<thead>
<tr>
<th></th>
<th>Corn</th>
<th>Switchgrass</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Harvest:</strong></td>
<td></td>
<td></td>
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<tr>
<td>Harvest Mass (kg ha(^{-1}) y(^{-1}))</td>
<td>8.746</td>
<td>13.450</td>
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<tr>
<td>Harvest Energy Content (MJ ha(^{-1}) y(^{-1}))(^b)</td>
<td>157,427</td>
<td>242,101</td>
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<tr>
<td><strong>Ethanol:</strong></td>
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<td></td>
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<tr>
<td>Gross Ethanol Production (MJ ha(^{-1}) y(^{-1}))</td>
<td>73,424</td>
<td>108,855</td>
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<tr>
<td>Gross Gasoline Equivalent (l ha(^{-1}) y(^{-1}))(^b)</td>
<td>2,335</td>
<td>3,461</td>
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<tr>
<td><strong>Electricity:</strong></td>
<td></td>
<td></td>
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<tr>
<td>Gross Electricity Production (MJ ha(^{-1}) y(^{-1}))(^c)</td>
<td>41,712</td>
<td>64,147</td>
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<td>Gross Electricity Production (kWh ha(^{-1}) y(^{-1}))</td>
<td>11,587</td>
<td>17,819</td>
</tr>
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*Table S1.* Gross transportation output of the bioenergy fuel cycle for ethanol and bioelectricity\(^a\).

*Campbell, Lobell, Field, Science, 2009*
<table>
<thead>
<tr>
<th>Make</th>
<th>Engine</th>
<th>Efficiency (city/highway)</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td></td>
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<td>kWh 100km⁻¹  1 100km⁻¹ km MJ⁻¹</td>
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<tr>
<td>Small Car</td>
<td>BEV</td>
<td>20/25  -  -  1.4/1.1</td>
<td>2001 Ford Th!nk, Ni-Cd, 27 kW AC</td>
</tr>
<tr>
<td>Small Car</td>
<td>ICV</td>
<td>-       7/6   0.5/0.6</td>
<td>2001 Suzuki Swift 4 cyl, 1.3 L, Man. 5-spd, Reg.</td>
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<tr>
<td>Midsize Car</td>
<td>BEV</td>
<td>18/16  -  -  1.5/1.7</td>
<td>2000 Nissan Altra, Lithium-Ion, 62 kW AC Ind.</td>
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<td>Midsize Car</td>
<td>ICV</td>
<td>-       11/8  0.3/0.4</td>
<td>2000 Nissan Altima 4 cyl, 2.4 L, Man. 5-spd, Reg.</td>
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<tr>
<td>Small SUV</td>
<td>BEV</td>
<td>17/21  -  -  1.7/1.3</td>
<td>2003 Toyota RAV4 2WD, Ni Metal Hydride</td>
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<tr>
<td>Small SUV</td>
<td>ICV</td>
<td>-       9/8   0.3/0.4</td>
<td>2003 Toyota RAV4 2WD 4 cyl, 2L, Man 5 spd, Reg.</td>
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<tr>
<td>Fullsize SUV</td>
<td>BEV</td>
<td>34/45  -  -  0.8/0.6</td>
<td>2002 Ford Explorer 2WD, PbAcid, 67kW AC Ind.</td>
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<td>Fullsize SUV</td>
<td>ICV</td>
<td>-       16/12 0.2/0.3</td>
<td>2002 Ford Explorer 2WD 6 cyl, 4L, Man, 5 spd Reg.</td>
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*aEPA recently updated efficiency ratings for all vehicles years to reflect more realistic driving conditions. Improved efficiency for ethanol relative to gasoline is small relative to differences between BEV and ICV efficiency.*

*bEnergy efficiency (mi MJ⁻¹) calculated based on gasoline LHV of 31.45 MJ L⁻¹.*
<table>
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<tr>
<th>Year</th>
<th>Demand</th>
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<th>Total (million tonnes)</th>
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<tr>
<td></td>
<td>per capita (kg)</td>
<td>all uses</td>
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<tr>
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