Biofuels: Costs and Potential for Mitigating Greenhouse Gases

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GHG Emissions from Transportation

Transportation sector accounts for about 30% emissions of GHG emissions in US.

Figure 2-2. 2003 Transportation Greenhouse Gas Emissions, by Source

Note: Territories are excluded even though they are reported in the U.S. inventory. Territories typically contribute less than 1 percent of national emissions.
…. And it will get worse: Tar Sands

Figure 2. Current and projected USA petroleum imports and fuel supply from tar sands from Venezuela and Canada. The percentage of tar sands in total production from Canada is reported for 2007 (44%) and estimated for 2020 (79%). The fraction of tar sands in Venezuela production is estimated for 2007 and 2020 based on IEA reports (World Resources Institute, http://www.wri.org/publication/content/10339 [February 2009]). Projections assume USA consumption and imports are constant from 2007 to 2020 (US Department of Energy), USA imports the same proportion of Canadian production (89%) and the same rate from Venezuela (1.36 mb/d), which increases tar sands production to 50%.

Liska et al., 2009
Some Options for Mitigating Emissions

Abatement Strategies

• Renewable Energy for Electricity Generation
• Low Carbon Fuels
• Electric Vehicles
• Increasing Fuel Economy
• Reducing Vehicle Miles Travelled

Policies

Renewable Portfolio Standards
Cap and Trade Policy
Low Carbon Fuel Standard
Technology specific: Biofuel Mandates and Tax Credits
Mitigating Climate Change: Role of Cropland

Renewable Energy

Providing biomass:
- Co-fired with coal in power plants
- Converted to cellulosic ethanol
- Ethanol from corn grain

Soil Carbon Sequestration

The world’s soils hold more carbon than is contained in the atmosphere and vegetation combined.
Soil Carbon Sequestration

Conservation tillage with corn and soybean: 0.3-0.5 MT/ha/yr
Perennial grasses 3 times higher 0.94-1.4 MT/ha/yr

Soil Carbon Accumulation Functions

Existing Soil Carbon Stocks

MT C/ha in 2003:
- 22.92 - 27.72
- 27.73 - 32.51
- 32.52 - 37.31
- 37.32 - 42.11
- 42.12 - 46.91
- 46.92 - 51.70
- 51.71 - 56.50
- 56.51 - 61.30
- 61.31 - 66.09
- 66.10 - 70.89
Life-Cycle Carbon Emissions from Electricity

All emissions during production of energy crops from planting to transportation to power plant

Soil carbon sequestration

Emissions displaced by energy crops on land otherwise under row crops

Compared to emissions from coal-fired electricity

![CO2 Emissions Per Kwh of Electricity](chart.png)
## Bio-Energy Production with 15% Co-firing Capacity

<table>
<thead>
<tr>
<th>Bioenergy price</th>
<th>($/GJ)</th>
<th>&lt;$2.4</th>
<th>$2.8</th>
<th>$3.2</th>
<th>$3.6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land under conservation till (%)</td>
<td>45.07</td>
<td>44.09</td>
<td>43.17</td>
<td>42.03</td>
<td></td>
</tr>
<tr>
<td>Land under miscanthus (%)</td>
<td>1.65</td>
<td>2.78</td>
<td>4.15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electricity generated with biomass (%)</td>
<td>5.53</td>
<td>9.16</td>
<td>13.27</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum distance to power plants from counties producing miscanthus (miles)</td>
<td>35</td>
<td>52</td>
<td>78</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total carbon mitigated in 15 Years (M T)</td>
<td>15.85</td>
<td>38.86</td>
<td>54.12</td>
<td>71.64</td>
<td></td>
</tr>
<tr>
<td>-coal displacement by biomass</td>
<td>21.29</td>
<td>35.27</td>
<td>51.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-sequestration by miscanthus</td>
<td>2.05</td>
<td>3.97</td>
<td>6.65</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-sequestration by conservation till</td>
<td>14.72</td>
<td>14.37</td>
<td>13.82</td>
<td>12.98</td>
<td></td>
</tr>
<tr>
<td>% of carbon emission mitigated in 15 years</td>
<td>4.32</td>
<td>10.59</td>
<td>14.75</td>
<td>19.53</td>
<td></td>
</tr>
<tr>
<td>Discounted present value of bioenergy subsidy ($M)</td>
<td>1074.2</td>
<td>2173.0</td>
<td>3721.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Discounted NPV of farm profit ($B)</td>
<td>48.1</td>
<td>48.3</td>
<td>49.0</td>
<td>50.2</td>
<td></td>
</tr>
</tbody>
</table>

Maximum price a power plant would be willing to pay for biomass based on energy content: $1.12/GJ
Area Under Miscanthus at $2.8/GJ and 15% Co-firing

Area Under Miscanthus at $3.6/GJ and 15% Co-firing
Direct Life Cycle GHG Emissions of Biofuels

![Diagram showing the lifecycle of biofuels and greenhouse gas emissions](image)

- **Producing Ethanol (EtOH) from Corn:** 0.78 million Btu Fossil Energy Input
- **Corn Farming:** Natural Gas
- **Fertilizer Production:** Liquefied Petroleum Gas, Electricity, Diesel Fuel
- **Corn Transportation:** Diesel Fuel
- **Ethanol (EtOH) Production:** Coal, Natural Gas, Electricity
- **Ethanol (EtOH) Transportation:** Diesel Fuel
- **Animal Feeds:** 1 million Btu of EtOH at Refueling Stations

**Producing Gasoline from Petroleum:** 1.23 million Btu Fossil Energy Input

- **Petroleum Recovery:** Natural Gas, Electricity
- **Petroleum Transportation:** Diesel Fuel, Natural Gas, Electricity
- **Petroleum Refining:** Refinery Gas, Natural Gas, Coal, Electricity
- **Gasoline Transportation:** Diesel Fuel
- **1 million Btu of Gasoline at Refueling Stations**

**Graph showing gCO2e/MJ for various biofuels and sources:**

- **Corn:** 94
- **Corn Stover:** 66
- **Miscanthus:** 60
- **Switchgrass:** 58
- **Low-input High-diversity Grass mix:** 63

**Comparing GHG emissions across different studies:**

- **Our study:** 15
- **Wu:** 13
- **Mclachlan:** 8
- **Spant.:** 5
- **Our study Case 1:** 9
- **Our study Case 2:** 21
- **Our study Case 3:** 17
- **Our study Case 4:** 17
- **Our study Case 5:** 22
- **Our study Case 6:** 11
- **Our study Case 7:** 12
- **Our study Case 8:** 35
- **Tilman:** 27
- **Macedo:** 21
- **Our study:** 25
Indirect Emissions

- These effects arise from interaction of markets for several commodities and across the globe

- Land may not be converted directly to be planted with bioenergy crop but planted to a crop displaced by biofuel crop

- Corn displaces soy in US
  - Reduction in soy exports from US
    - Increase in soy acreage in Brazil displacing pastures
      - Forest cleared in Brazil for pasture land
        - Results in release of carbon stored in trees/soil
Indirect Emissions

*Emissions accompanying induced expansion or intensification of agriculture*

- Example of extensification is induced conversion of non-cropland such as pastures or forestland to agriculture

- Example of intensification is greater use of energy-intensive inputs like fertilizers in response to increase in output prices

- Unlike direct emissions they cannot be traced to a single biofuel producer and they may occur at locations far away from a biofuel production site
Biofuels and GHG emission

Controlling both direct & indirect emissions is crucial

Comparing Gasoline and US Corn Ethanol

<table>
<thead>
<tr>
<th>GHG emissions in gCO2e/MJ</th>
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<tbody>
<tr>
<td>US Ethanol Today</td>
</tr>
<tr>
<td>Scenario 1</td>
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<tr>
<td>Scenario 2</td>
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<tr>
<td>Scenario 3</td>
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<tr>
<td>Scenario 4</td>
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</tbody>
</table>

- **Indirect land use change emissions**
- **Direct Emissions**

Gasoline 94 gCO2e/MJ

Direct emissions from Farrel et al., Indirect from Searchinger et al.

Scenario 1: Coal based biorefining (increases direct emissions)
Scenario 2: Natural gas based biorefining (lowers direct emissions)
Scenario 3: NG based biorefining and Indirect emissions equal to 1/3rd of Searchinger et al.’s estimate
Scenario 4: NG gas based biorefining, 39% improvement in corn yield, 25% reduction in energy for processing and indirect emissions equaling 1/3rd of Searchinger et al.’s estimate
Figure 3. Greenhouse gas emissions intensity of transportation biofuels (gray bars) and fossil fuels (black bars), with inclusion of indirect land use emissions in the life cycle (hatched bars) and indirect emissions from gasoline originating in the Persian Gulf. All values are averages, and error bars indicate maximum estimates.

Liska et al., 2009
Need for High Yielding Feedstocks

Biofuel Yields with Alternative Feedstocks

Gallons Per Acre

Barley - Wheat - Corn - Sugarbeet - Sugarcane - Sweet Sorghum - Corn Stover - Switchgrass - Miscanthus
Costs and yields of energy crops

Costs of Switchgrass, $/t

Yields, t/ha

Costs of miscanthus, $/t

Yields, t/ha
Cost of Production of Ethanol by Feedstock

- Feedstock Cost
- Opportunity Cost of Land
- Fuel Conversion
- Transport from Brazil to US

Feedstock:
- Switchgrass
- Miscanthus
- Corn Stover
- Corn (C-S)
- Corn (C-C)
- Sugarcane $1 = R1.55
- Sugarcane $1 = R2.62
- Sugarcane (Co-Gen) $1 = R1.55
- Sugarcane (Co-Gen) $1 = R2.62

$/gallon
Costs of ethanol production

Switchgrass

Miscanthus

$/gallon

$t/hectare

Low cost
High cost
Yield

Minnesota
South Dakota
Iowa
Illinois
Nebraska
Wisconsin
North Dakota
Kansas
New York
Pennsylvania
Texas
Indiana
Michigan
Georgia
Louisiana
Ohio
Tennessee
Maryland
Mississippi
Virginia
North Carolina
Kentucky
New Jersey
Ohio
West Virginia
South Carolina
Florida
Alabama
Missouri
Arkansas
Texas
Minnesota
Florida
Illinois
Iowa
Louisiana
Wisconsin
South Dakota
Nebraska
Pennsylvania
New York
North Dakota
Indiana
Michigan
Ohio
Kansas
Georgia
New Jersey
Maryland
Mississippi
Kentucky
Virginia
Tennessee
West Virginia
Missouri
North Carolina
Arkansas
Alabama
South Carolina

0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
$t/hectare

0
2
4
6
8
10
12
14
16
18
Policy Intervention: Carbon Pricing

- Encourage substitution from gasoline to biofuels
- Reduction in Vehicle miles travelled
- Provide incentives for innovation of low carbon alternatives
- But need to be balanced with effects on higher food production costs and food prices
- Also raise cropland rents by inducing diversion of land to biofuels
Implications of a Carbon Tax for Gasoline and Credit Biofuels
Biofuel Mandates and Tax Credits

Biomass Crop Assistance Program; Subsidies for corn ethanol and cellulosic ethanol
Biofuel Policy May Not Be Good Climate Policy

• Mandates displace gasoline and lower its price
• Could lower the price of blended fuel and encourage greater demand for vehicle miles
• Biofuel tax credits further exacerbate this effects
• Do not prevent imports of oil tar sands
Summary

- Biofuels have potential to lower GHG intensity – extent differs across feedstocks
- Feedstocks with lower GHG intensity more expensive – need for government policy
- Policy used for encouraging biofuels could create perverse incentives for greater fuel consumption and increase GHG emissions
- If GHG mitigation is the motivation for encouraging biofuels then a cap and trade or carbon tax is the cost effective approach.