Food and Fuel: Land Efficient Animal Feeds Enable Large Energy & Environmental Benefits

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“[I]t's a crime against humanity to convert agricultural productive soil into soil... which will be burned into biofuel.”

Jean Ziegler, UN Special Rapporteur, 2007
Indirect land use change - are biofuels no longer sustainable?

<table>
<thead>
<tr>
<th>Source of fuel</th>
<th>Gasoline</th>
<th>Biomass ethanol</th>
<th>Ethanol + indirect land use change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feedstock</td>
<td>4</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Refining fuel</td>
<td>15</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Vehicle operation (burning fuel)</td>
<td>72</td>
<td>71</td>
<td>71</td>
</tr>
<tr>
<td>Feedstock carbon uptake from atmosphere (GREET)</td>
<td>0</td>
<td>-62</td>
<td>-62</td>
</tr>
<tr>
<td>Land-use change</td>
<td>-</td>
<td>-</td>
<td>111</td>
</tr>
<tr>
<td>Total GHGs</td>
<td>92</td>
<td>27</td>
<td>138</td>
</tr>
<tr>
<td>% Change in net GHGs versus gasoline</td>
<td>-</td>
<td>-70%</td>
<td>50%</td>
</tr>
</tbody>
</table>

All values are in g CO2 eq / km driven

Not asking the right questions

- We cannot force bioenergy into the current agricultural landscape and expect it to work
  - Agriculture has changed before; it can change again

- We must examine the actual uses of land rather than relying on intuitive “gut reactions”
  - Most agricultural land is used for animal feed, **NOT** direct human consumption
  - Cropland is currently not used efficiently; we actually have more than enough land

- Solution: new technologies for better animal feed and improved productivity of land
Leaf Protein Concentrates

- Leaf protein readily abundant, but trapped with indigestible fibrous material
- Solution: separate protein from fiber
  - Leaf protein replaces soy meal & is more land efficient
  - Fiber can be used for ethanol production
- Successfully produced at commercial scales

<table>
<thead>
<tr>
<th>Crop</th>
<th>Average Yield (tons/acre/year)</th>
<th>Protein Content (dry mass %)</th>
<th>Protein Produced (tons/acre/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Switchgrass</td>
<td>5.0 - 10</td>
<td>5 - 10%</td>
<td>0.25 - 1.0</td>
</tr>
<tr>
<td>Soybeans</td>
<td>1.2 - 1.4</td>
<td>40%</td>
<td>0.5 - 0.6</td>
</tr>
<tr>
<td>Alfalfa</td>
<td>3.7 - 5.0</td>
<td>20 - 25%</td>
<td>0.8 - 1.2</td>
</tr>
<tr>
<td>Mixed forages</td>
<td>3.3 - 4.6</td>
<td>15 - 25%</td>
<td>0.5 - 1.2</td>
</tr>
<tr>
<td>Double crop</td>
<td>1.0 - 2.5</td>
<td>10 - 20%</td>
<td>0.1 - 0.5</td>
</tr>
</tbody>
</table>
AFEX-Treated Fibrous Feeds

- Problem: Energy in the form of cellulose
  - Early Forages - low yields, expensive
  - Late Forages - indigestible, low nitrogen
- Partial solution: Gaseous ammoniation
  - Only modest improvements in digestibility seen
  - Increases nitrogen content
- AFEX - Ammonia Fiber Expansion
  - A leading pretreatment for biofuels via sugar platform
  - Better fiber disruption than conventional ammoniation for forages—better animal feed
## Total Digestible Nutrients, Net Energy for Lactation, and Crude Protein

<table>
<thead>
<tr>
<th></th>
<th>TDN % DM</th>
<th>NEL Mcal/lb</th>
<th>CP % DM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn grain</td>
<td>88.7</td>
<td>0.91</td>
<td>9.4</td>
</tr>
<tr>
<td>Corn silage</td>
<td>68.8</td>
<td>0.66</td>
<td>8.8</td>
</tr>
<tr>
<td>Orchardgrass hay</td>
<td>63.1</td>
<td>0.62</td>
<td>18.1</td>
</tr>
<tr>
<td>Alfalfa hay</td>
<td>58.9</td>
<td>0.58</td>
<td>20.2</td>
</tr>
<tr>
<td>AFEX Corn Stover</td>
<td>75.6</td>
<td>0.79</td>
<td>17.2</td>
</tr>
<tr>
<td>AFEX Switchgrass - late</td>
<td>63.0</td>
<td>0.67</td>
<td>14.6</td>
</tr>
</tbody>
</table>

All values except AFEX materials obtained from *Nutrient Requirements of Dairy Cattle*, NRC 2001
Double Cropping

- Grow crops over winter and spring on corn or soy land while still growing corn/soy
  - Does **NOT** require new land
  - Increases corn stover than can be harvested
  - Can be used for fuel, protein, forage, etc

Holt, MI: May 5, 2005
Determining the Technical Potential

- Take all current cropland dedicated to animal feed, feed exports, ethanol production, and idle land and rethink how we use it
  - Approx. 70% of US cropland (114 million ha)
- Rebuild while meeting current animal feed and export requirements
  - Energy, protein, and fiber
  - Ruminants and non-ruminants
- Solve cropland use & end-use to maximize ethanol production/minimize GHG emissions
<table>
<thead>
<tr>
<th>Crop</th>
<th>Land</th>
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<th>Land</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>31.4</td>
<td>Alfalfa</td>
<td>8.2</td>
</tr>
<tr>
<td>Domestic feed</td>
<td>16.4</td>
<td>Other haylage</td>
<td>16.7</td>
</tr>
<tr>
<td>Ethanol</td>
<td>8.3</td>
<td>Cropland for pasture</td>
<td>14.5</td>
</tr>
<tr>
<td>Export</td>
<td>6.7</td>
<td>Reserved/Idle land</td>
<td>15.4</td>
</tr>
<tr>
<td>Soybean</td>
<td>25.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Domestic feed</td>
<td>15.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Export</td>
<td>9.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Failed Cropland</td>
<td>3.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total row crops</strong></td>
<td>59.5</td>
<td><strong>Total forage land</strong></td>
<td>54.7</td>
</tr>
<tr>
<td><strong>Total land</strong></td>
<td>114.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Environmental considerations

- On-farm emissions: DAYCENT modeling
  - Average over 60 years
  - 11 different locations throughout Midwest
- Transportation emissions to and from refineries
- Refining emissions
  - GREET model - corn ethanol
  - NREL/Dartmouth model - cellulosic ethanol
  - In-house estimates - protein, AFEX feeds
- End-use - Assumed to burn cleanly
  - Ethanol - displaces gasoline on energy basis
  - Lignin - displaces electricity using current US fuel makeup
Limitations of the study

- Does not consider economics
  - Farmers may not choose most land efficient options if there is better economic in another approach
- Does not consider logistics
  - Not all idle land may be available
- Does not consider cropland for human consumption, forest land, or grassland pasture and rangeland
  - Additional improvements in biofuel production and GHG reductions are possible
Current vs Future Land Use

- Using the same land, total biomass production increases by 2.5 times
- Displaces 50% of gasoline use and 5% of US electricity use
Current Land Use

End Use
- Ruminant Feed (222 Tg)
- Export (93 Tg)
- Ethanol Fuel (27 Tg) 825 EJ
- CO₂ (29 Tg)

Crops
- Protein Meal (39 Tg)
- Vegetable Oil (9 Tg)
- Protein Forage (195 Tg)

Farm Land
- Grassland (31.2 million ha)
- Alfalfa (8.2 million ha)
- Idle Land (18.4 million ha)
- Row Crops (56.5 million ha)
- Oil Seeds (80 Tg)
- Grain (315 Tg)
Why so different?

- **Idle land:** ~40 million acres
  - Convert to switchgrass at ~500 gal/acre
  - ~20 billion gallons/yr
- **Grass hay and pasture:** ~75 million acres
  - Average yield is 3 times smaller than switchgrass (assumed to be 6.2 ton/acre/yr)
  - Average yield is slightly less than cover crop yield
  - Eliminated land leads to ~35 billion gallons/yr
- **Corn stover removal:** ~100 million acres
  - Does not include ~25% going to animal feed
  - ~15 billion gallons/yr
- **Corn grain:** ~20 million acre increase
  - Not as much needed due to stover/DGS as feed
  - Not as much soy needed due to LPC production
  - Grain ethanol is ~20 billion gallons/yr
Maximum Ethanol Production Tracks with Maximum CO2 Reduction

Very little difference in performance over a range of assumptions
## Greenhouse Gas Emissions

### Total US Greenhouse Gases (2009): 6950 Tg

<table>
<thead>
<tr>
<th>Category</th>
<th>Displaced amount</th>
<th>GHG Emissions (Tg CO2-eq/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>On Farm GHG</td>
<td>-</td>
<td>95.73</td>
</tr>
<tr>
<td>Transportation GHG</td>
<td>-</td>
<td>27.99</td>
</tr>
<tr>
<td>Processing GHG</td>
<td>-</td>
<td>165.61</td>
</tr>
<tr>
<td>Ethanol Transportation GHG</td>
<td>-</td>
<td>11.71</td>
</tr>
<tr>
<td>Gasoline displaced</td>
<td>399.8 GL</td>
<td>-758.9</td>
</tr>
<tr>
<td>Electricity Displaced</td>
<td>216.7 TW*hr</td>
<td>-163.4</td>
</tr>
<tr>
<td>Current GHG Emissions</td>
<td>48.9 Tg/yr</td>
<td>-48.9</td>
</tr>
<tr>
<td>Net GHG Emissions</td>
<td>-</td>
<td>-670.8</td>
</tr>
</tbody>
</table>
GHG Emission Contributions

- AFEX-treated feeds and LPCs consume large amounts of fossil energy
  - Solution: co-locate with ethanol facility
- Slightly higher on-farm GHG emissions
  - More intensive land use
  - Low on-farm GHG emissions for switchgrass
  - No difference for double crops
  - Little difference for length of corn rotation
- Fossil fuel reduction is dominant GHG driver
Other Sustainability Issues

- Net soil organic carbon increases in this process
  - Great improvements with switchgrass over pasture/grass hay
  - SOC doubles when double crops are included
- Nitrate leaching increases ~3-fold
  - Longer corn rotations
  - 5-fold higher emissions from switchgrass than grass hay
  - May not occur for native prairies or miscanthus
Ways to Reduce Nitrate Leaching

- Much more double cropping
- Improve plant fertilizer use efficiency
- Precision agriculture
- Controlled release fertilizers
- Dietary changes
- Better landscape design
  - Deep rooted perennials in row crop systems
Sensitivity Analysis

Animal feed requirements and switchgrass energy crop yields dominate

<table>
<thead>
<tr>
<th>EtOH Change</th>
<th>Feed Consumption</th>
<th>CBC Yields</th>
<th>Exports</th>
<th>Cover Crop Land</th>
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Percent Change in Ethanol Production or GHG Reductions

-30%  -20%  -10%  0%  10%  20%  30%

25% Increase
25% Decrease
Sensitivity Analysis

High double-cropping desired
Further Improvements

- Can we replace all US gasoline?
  - Lift constraint on AFEX treated feeds
  - Increase energy crop yields to 12 ton/acre
  - Decrease exports by 50%
  - Increase row crop yields by 10%
  - Increase cover crops to 67% of rotation land
  - End result: 102% of US gasoline use

- Can we replace all US petroleum imports?
  - Lift constraint on AFEX treated feeds
  - Increase energy crop yields to 15 ton/acre
  - Eliminate exports
  - Decrease meat consumption by 20%
  - Increase row crop yields by 10%
  - Cover crops on all land
  - End result: 102% of total imports
Conclusions

- Large-scale biofuel economy is possible through intensely managed lands
  - 50% of US gasoline consumption
  - 10% of greenhouse gas emissions
- Double crops, animal feed requirements, and energy crop yields have the greatest impact on bioenergy production and environmental benefits
- Must study & implement ways to reduce nitrate leaching
- Great opportunity for productive collaboration between farmers, biofuel producers, government agencies & environmental groups
Acknowledgements

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Our BCRL Team