Life Cycle Greenhouse Gas Emissions from Biofuels: Variability, Uncertainty, and Steps Toward Accurate Regulation

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Life Cycle Greenhouse Gas Emissions from Biofuels: Variability, Uncertainty, and Steps Toward Accurate Regulation

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Governors’ Agriculture, Energy, and Sustainability Roundtable, Jan. 28, 2010
Washington, D.C., Governors’ Biofuels Coalition
Today’s Presentation

a) Variability in life cycle greenhouse gas (GHG) emissions from corn-ethanol:
   - biorefineries
   - cropping systems
   - co-product feeding to livestock

b) EPA regulation of life cycle GHG emissions from biofuels & use of life cycle analysis (LCA):
   - uncertainties & inaccuracies
   - indirect effects

c) Building accurate knowledge infrastructure, theory, and research teams for accurate LCA methods for biofuels
~90% of U.S. ethanol production uses corn grain at new natural gas-powered dry mills

Source: Liska AJ & Perrin RK. Energy and Climate Implications for Agricultural Nutrient Use Efficiency. IN: GIS Applications in Agriculture—Nutrient Management for Improved Energy Efficiency. CRC Press. in press
New survey data shows improved energy efficiency at biorefineries & reduced life cycle GHG emissions

Avg. natural gas use in 2001
70% of life cycle emissions

 Avg. natural gas use in newer plants, less variability

GHG emissions from corn production depend on crop yields, nitrogen fertilizer rates, and cropping inputs, producing variability in ethanol life cycle emissions.

Life-cycle GHG reduction compared to gasoline w/ new natural gas-powered ethanol plant

GHG emissions credits for distillers grains depend on types produced, livestock fed, and cropping region (Wet vs. Dry Distillers) (Beef Cattle vs. Dairy/Swine) (State)

Soil and climate variability determine regional life cycle GHG-intensities of corn-ethanol

Biofuel production is a complex system of systems, crop production, biorefinery, co-products, fossil fuel inputs, etc.

Variability in space and time for cropping, biorefineries, and distillers grains feeding leads to variability and uncertainty in LCA results.

Small changes in the magnitude of sensitive parameters dramatically change LCA results: crop and biorefinery yields, N₂O emissions, biorefinery natural gas and electricity, lime appl. rates.

Empirical data are scarce for key aspects of the system.
LCA results depend on the depth and rigor of analysis.

“Standardized” LCA methods are being developed for biofuels (EPA, California), but none currently exist. The academic community vigorously discusses biofuel LCA methods, but the science is currently far from clear.
EISA 2007 and EPA Regulation

- Requires reductions in life cycle GHG emissions (CO₂, CH₄, N₂O) for corn-ethanol vs gasoline by **20%**
- EPA RFS2 proposes to use a range of hypothetical average efficiencies to determine the GHG emissions performance for different biorefinery types for corn-ethanol

**Problem:**

Significant variability is observed for many parameters & hypothetical averages do not accurately represent the GHG emissions from individual biofuel producers

**Therefore:**

Frequent surveys of data on biofuel producers, regional cropping, & livestock feeding are necessary **to accurately assess GHG emissions reductions for regulated facilities**
“...it would require an extremely complex assessment and administratively difficult implementation program to track how biofuel production might continuously change from month to month or year to year [state to state]. Instead, it seems appropriate that each biofuel be assessed a level of GHG performance that is constant over the implementation of this rule, allowing fuel providers to anticipate how these GHG performance assessments should affect their production plans...”

### Assessing the Complexity of Biofuel Production: Inventory of Life Cycle GHG Emissions for Corn-Ethanol using One (1) Model

<table>
<thead>
<tr>
<th>Component</th>
<th>GHG emission category</th>
<th>gCO₂e MJ⁻¹</th>
<th>Mg CO₂e*</th>
<th>% of LC</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Crop Production</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrogen fertilizer, N</td>
<td></td>
<td>4.26</td>
<td>34,069</td>
<td>7.46</td>
</tr>
<tr>
<td>Phosphorus fertilizer, P</td>
<td></td>
<td>0.953</td>
<td>7,618</td>
<td>1.67</td>
</tr>
<tr>
<td>Potassium fertilizer, K</td>
<td></td>
<td>0.542</td>
<td>4,337</td>
<td>0.950</td>
</tr>
<tr>
<td>Lime</td>
<td></td>
<td>2.82</td>
<td>22,577</td>
<td>4.95</td>
</tr>
<tr>
<td>Herbicides</td>
<td></td>
<td>1.51</td>
<td>12,079</td>
<td>2.65</td>
</tr>
<tr>
<td>Insecticides</td>
<td></td>
<td>0.018</td>
<td>141</td>
<td>0.031</td>
</tr>
<tr>
<td>Seed</td>
<td></td>
<td>0.193</td>
<td>1,540</td>
<td>0.337</td>
</tr>
<tr>
<td>Gasoline</td>
<td></td>
<td>0.355</td>
<td>2,837</td>
<td>0.621</td>
</tr>
<tr>
<td>Diesel</td>
<td></td>
<td>1.73</td>
<td>13,848</td>
<td>2.65</td>
</tr>
<tr>
<td>LPG</td>
<td></td>
<td>1.24</td>
<td>9,932</td>
<td>2.18</td>
</tr>
<tr>
<td>Natural gas</td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Electricity</td>
<td></td>
<td>0.348</td>
<td>2,785</td>
<td>0.610</td>
</tr>
<tr>
<td>Depreciable capital</td>
<td></td>
<td>0.268</td>
<td>2,144</td>
<td>0.470</td>
</tr>
<tr>
<td>N₂O emissions**</td>
<td></td>
<td>14.1</td>
<td>112,550</td>
<td>24.7</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td>28.3</td>
<td>226,456</td>
<td>49.6</td>
</tr>
<tr>
<td><strong>Biorefinery</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Natural gas input</td>
<td></td>
<td>19.7</td>
<td>157,356</td>
<td>34.5</td>
</tr>
<tr>
<td>NG Input: drying DGS†</td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Electricity input</td>
<td></td>
<td>6.53</td>
<td>52,201</td>
<td>11.4</td>
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<tr>
<td>Depreciable capital</td>
<td></td>
<td>0.458</td>
<td>3,663</td>
<td>0.802</td>
</tr>
<tr>
<td>Grain transportation</td>
<td></td>
<td>2.11</td>
<td>16,851</td>
<td>3.69</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td>28.8</td>
<td>230,071</td>
<td>50.4</td>
</tr>
<tr>
<td><strong>Co-Product Credit</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diesel</td>
<td></td>
<td>0.216</td>
<td>1,731</td>
<td>0.379</td>
</tr>
<tr>
<td>Urea production</td>
<td></td>
<td>-2.62</td>
<td>-20,956</td>
<td>-4.59</td>
</tr>
<tr>
<td>Corn production</td>
<td></td>
<td>-11.4</td>
<td>-91,501</td>
<td>-20.0</td>
</tr>
<tr>
<td>Enteric fermentation-CH₄</td>
<td></td>
<td>-2.64</td>
<td>-21,102</td>
<td>-4.62</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td>-16.5</td>
<td>-131,828</td>
<td>-28.9</td>
</tr>
<tr>
<td>Transportation of Ethanol from Biorefinery</td>
<td></td>
<td>1.40</td>
<td>11,196</td>
<td>0</td>
</tr>
<tr>
<td><strong>LIFE-CYCLE NET GHG EMISSIONS</strong></td>
<td></td>
<td>42.0</td>
<td>335,895</td>
<td>100</td>
</tr>
<tr>
<td>GHG-intensity of ethanol, g CO₂e MJ⁻¹</td>
<td></td>
<td>42.0</td>
<td>335,895</td>
<td></td>
</tr>
<tr>
<td>GHG-intensity of gasoline, g CO₂e MJ⁻¹</td>
<td></td>
<td>92.0</td>
<td>735,715</td>
<td></td>
</tr>
<tr>
<td><strong>GHG reduction relative to gasoline, %</strong></td>
<td></td>
<td>50.0</td>
<td>399,819</td>
<td>54.3%</td>
</tr>
</tbody>
</table>

Modeling Complexity in Biofuel Life Cycle Emissions

- **Problem:** Most biofuel LCA’s use one model that has 300-400 parameters, yet lengthy controversy exists due to inconsistent use of data sources and system boundaries.
- Highly controversial Searchinger study of indirect land use emissions combined 2 complex models: GREET & FAPRI.
- EPA RFS2 LCA methodology combines 6-8 highly complex models to capture direct & indirect emissions: GREET, FASOM, ASPEN, MOVES, FAPRI, NEMS, and perhaps GTAP & DAYCENT in total having tens of thousands of parameters.

No similar LCA is found in the scientific literature.

- RFS2 approach will likely still not capture all significant indirect emissions (Liska & Perrin 2009), and a reasonable level of accuracy by this method is nearly unattainable due to uncertainty in projected parameters values (Kim, Kim, Dale 2009).
Single Models using 300-400 Parameters give Highly Variable Results

Corn/Wheat to Ethanol

Presentation: Stefan Unnasch, Review of Transportation Fuel Life Cycle Analysis and CA GREET, CRC WORKSHOP ON LIFE CYCLE ANALYSIS OF BIOFUELS, Argonne National Laboratory, October 20-21, 2009
http://www.crcao.org/workshops/LCA%20October%202009/LCAindex.html
Emissions from Indirect Land Use Change Projections Depends on Models Used & Many Implied Assumptions

Change in International Crop Acres from 2.6 Billion More Gallons of Corn Ethanol

Presentation: Bruce A. Babcock, Overview of the CARD/FAPRI Modeling System
CRC WORKSHOP ON LIFE CYCLE ANALYSIS OF BIOFUELS,
Argonne National Laboratory, October 20-21, 2009
http://www.crcao.org/workshops/LCA%20October%202009/LCAindex.html
Transparency & Complex Indirect Effects in Regulations

- **Problem**: When using tens of thousands of parameters, can regulatory LCA be 100% transparent? Likely No.
- Any regulatory LCA methodology must approach complete transparency of calculations, parameter values, and references for data used to ensure accuracy.
- Evaluating all indirect effects in one LCA is excessively complex, particularly for contentious EPA regulation.
- *RFS2 LCA methods should only be as complex as can be practically & transparently reviewed & supported by accurate data, within acceptable uncertainty limits.
- If sufficient transparency & accuracy are not achieved, indirect effects should be excluded from RFS2.
Proposed Land Grant Biofuel LCA Working Group

• Provide integrated scientific leadership & assistance in regulatory LCA to help ensure accuracy, rigor and fairness by building consensus in modeling approaches & integrating information from stakeholders & parallel working groups

• Proposed requirements for researchers in working group:
  – Faculty from Land Grant universities
    (non-industry perspective with access to broad research resources)
  – Published scientific articles on biofuel LCA & related issues
    (experience in nuances of LCA research)
  – Involved in agricultural research & closely related disciplines
    (experience directly in bioenergy systems—as corn-ethanol is the dominant fuel under scrutiny, those with direct experience in these systems will have best insight)
Proposed Land Grant Biofuel LCA Working Group

In total, these Land Grant faculty have published 80+ scientific articles directly on LCA of biofuels and closely related agricultural & engineering issues.
Proposed **Land Grant Biofuel LCA Working Group**

**Proposed collaborators:**

- Research resources at Land Grant universities
- USDA, DOE, EPA, DOT
- Midwestern Governors' Association — *LCFS Working Group*
- National Research Council
- Industry
- Roundtable on Sustainable Biofuels (EU)

**How is our approach different than these groups?**

- Critical mass of academic researchers that have: 1) *direct experience with biofuel LCA*, 2) *could provide sustained effort (~5+ yrs)*, 3) independent from *oil or biofuel industries*
Goals, Land Grant Biofuel LCA Working Group

• To facilitate well-informed & impartial discussion, evaluation, and analysis of regulatory LCA methods

• Identify & develop appropriate background theory, methodology (e.g. system boundaries), identify data gaps & data acquisition approaches, provide sensitivity analysis, and hold yearly conferences to build on and engage others

• Our experience with the California LCFS regulatory process, which has strongly influenced the RFS2 approach, leads us to believe that regulators have limited experience with LCA of biofuels, the current choice of LCA methods seem to be politically influenced (not derived from the most accurate methods found in the scientific literature), and more objective & sustained input from the scientific community is needed to ensure accuracy & fairness
Funding support

- Western Governor’s Association
- US Department of Agriculture
- US Department of Energy
- DOE Great Lakes Bioenergy Research Center
- University of Nebraska Center for Energy Sciences Research
- Biomass Conversion Research Laboratory, Michigan State University
- Environmental Defense Fund

Research Collaborators

- Prof. Kenneth Cassman, Agronomy, Univ. Nebraska
- Dr. Seungdo Kim, Chemical Eng., Mich. State Univ.
- Prof. Richard Perrin, Ag. Econ., Univ. Nebraska
- Profs. Terry Klopfenstein & Galen Erickson, Animal Science, Univ. Nebraska
Selected References

Science of indirect effects is in its infancy, regulation of one indirect effect (deforestation) and one fuel (ethanol) is neither balanced nor equitable.

Table 1. Additional factors and uncertainties that determine net changes in indirect greenhouse gas emissions from transportation fuel production. Emissions units in TgCO₂e yr⁻¹.

<table>
<thead>
<tr>
<th>Factors Influencing Indirect GHG Emissions</th>
<th>Contribution to Atmospheric GHGs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Biofuels</strong></td>
<td>Marginal Changes Upon Biofuel Production</td>
</tr>
<tr>
<td>Deforestation and Grassland Conversion</td>
<td>+ (127†)</td>
</tr>
<tr>
<td>Rice Expansion²</td>
<td>+</td>
</tr>
<tr>
<td>Livestock Decline</td>
<td>– (58‡‡)</td>
</tr>
<tr>
<td>Reclamation of Dry and Degraded Lands⁵</td>
<td>–</td>
</tr>
<tr>
<td>Substitution of Corn for Soybean and Wheat⁶</td>
<td>–</td>
</tr>
<tr>
<td>Geographic Pattern of Land Conversion⁷</td>
<td>+/-</td>
</tr>
<tr>
<td>Climate Policies for Forest Maintenance⁸</td>
<td>–</td>
</tr>
<tr>
<td><strong>Petroleum</strong></td>
<td>Additional &amp; Marginal Emissions Not Currently Included</td>
</tr>
<tr>
<td>Tar Sands and Unconventional Fuels⁹</td>
<td>+</td>
</tr>
<tr>
<td>Indirect Military Fuel Use and Infrastructure⁴</td>
<td>+ (187§)</td>
</tr>
<tr>
<td>Processing and Transportation Losses⁴</td>
<td>+</td>
</tr>
</tbody>
</table>

US military fuel use / infrastructure to secure foreign oil: ~$104 billion per year [not including complete Iraq costs]

Survey data needs for biorefineries

• Key parameters for individual biofuel producers, and regional crop/livestock, should be monitored on an annual or biannual basis to ensure accuracy:

Biorefinery:
  1) grain used per unit of anhydrous ethanol yield, kg L\(^{-1}\)
  2) natural gas use per unit of anhydrous ethanol, MJ L\(^{-1}\)
  3) electricity use per unit of anhydrous ethanol, kWh L\(^{-1}\)

Crop production and Livestock:
  4) on-farm fuel & nitrogen fertilizer use for corn production
  5) types of co-products produced and their characteristics:
     % wet, modified, & dry distillers grains (moisture %)

• These surveys can be coordinated with EPA’s Mandatory Reporting of Greenhouse Gases*, starting in Jan. 2010

Variability in co-product GHG emissions credits for individual biorefineries/regions depends on type of CP produced and livestock class fed.

Results of BESS model simulations

Source: Bremer et al. Journal of Environmental Quality, 2010
Life cycle GHG emissions intensity and % reductions for corn-ethanol compared to gasoline, depends on **co-product variability & energy savings for drying CP**

Source: Bremer et al. *Journal of Environmental Quality*, 2010

Results of BESS model simulations

Gasoline: 97.7 gCO₂e/MJ