Life Cycle Assessment and Winter Cropping Systems

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Penn State University Cover Crop Crop Meeting
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Overview

• What is life cycle Assessment?
• Why and how we use LCA to estimate the C-intensity of biofuels: background on crop and fuel pathway:
  – GHG intensity/C “footprint” of fuel pathway
  – Renewable Fuel Standard (RFS2)
• Why this is relevant for winter crops
• LCA model development
• LCA software tools (SimaPro, GaBi, GREET, GHGenius)
• Case study: Winter barley-to-ethanol, Osage Bioenergy
What is Life Cycle Assessment?

Life cycle assessment (LCA) is a decision making tool to identify environmental burdens and evaluate the environmental consequences of a product, process or service over its life cycle from cradle to grave (i.e. from extraction of resources through to the disposal of unwanted residuals).
Life Cycle Assessment Framework

Goal and scope definition

Inventory analysis

Impact assessment

Interpretation

**Definition of LCA** according to ISO 14040:
LCA is a technique [...] compiling an inventory of relevant inputs and outputs of a product system; evaluating the potential environmental impacts associated with those inputs and outputs; and interpreting the results of the inventory and impact phases in relation to the objectives of the study.

Source: ISO 14040
What is a Product Life Cycle?

The boxes are process groups called life cycle stages (system components). The arrows are economic material flows (relationships between system components).
Well-to-wheel (WTW) analysis

Adapted from Wang (2004)
Impact Assessment
Impact categories proposed by UNEP/SETAC Life Cycle Initiative in 2003

Midpoint categories
(environmental problems)

- Photochemical oxidant formation
- Human toxicity
- Ozone depletion
- **Climate change**
  - Acidification
  - Eutrophication
  - Ecotoxicity
  - Land use impacts
- Species & organism dispersal
- Abiotic resources depletion
- Biotic resources depletion

Source: Int J of LCA 9(6) 2004
Impact Assessment
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Source: Int J of LCA 9(6) 2004
Tools: Simapro LCA Software

• Tool that operates as database and computational tool:
  – Like MS Access and Excel in 1 tool

• Data sets contain “cradle-to-gate” modules for specific end products, e.g., ingot steel
  – Traces inputs/outputs “back to earth”

• Visual tool for constructing material flow diagrams for LCA and calculating life cycle environmental impacts, e.g., C-footprint

• Other tools: GaBi (private); GREET, GHGenius (public)
How LCA is Used for Policy Decisions on Biofuels: What are RFS2 Requirements?

- The standard requires a certain volumetric production schedule between 2008-2022
- There are 3 categories of biofuels:
  - Renewable: corn feedstocks allowed; ↓GHGs by 20%
  - Advanced: non-corn feedstocks that ↓GHGs by 50%
  - Cellulosic: biomass-based feedstocks that ↓GHGs by 60%
- LCA models are used to construct comprehensive accounts of biofuel C-footprint
Example: Winter barley, an advanced fuel?

- Winter barley is a starch-based feedstock;
- Produced in winter when certain agricultural fields are normally left fallow (subject to ag. Sector economics)
- Therefore, can winter barley converted to ethanol reduce life cycle GHG emissions relative to gasoline by 50%?
- How do we measure this?
- What are the variables to consider?
Basis of comparison

• In LCA, this is known as the functional unit (FU)

• Define FU for fuels: 1 MJ (energy unit)
  – Assumption: 1 MJ of gasoline can provide propulsion at the same efficiency as 1 MJ of ethanol

• Adjust inputs/outputs based on lower heating value (LHV) of ethanol
  – LHV gasoline: 33 MJ/L
  – LHV ethanol: 21 MJ/L

• Construct LCA model for barley-to-ethanol
Case study: Winter Barley and Low Carbon fuels

• Advanced fuel status under RFS2
  – 50% reduction in life cycle GHG emissions relative to gasoline
  – Assessment of land use change
    • Economic models employed

• Interest on the east coast U.S.
  – Winter crops and water quality
  – Maintaining agricultural lands
    • Anticipated positive impacts on land use
    • Not interfering with soybean crops

• Develop a LCA model to evaluate the life cycle GHG emissions of:
  – w. barley-to-ethanol
Why Winter Barley?

- Low or no anticipated indirect land use implications → use existing fallow land → maintain soybean yields
- Reduces nutrient leaching and runoff into surface and groundwater
- Erosion protection
- Economic benefits to participating farmers
- The growth of winter barley is promoted by the Chesapeake Bay Commission as a means of reducing nutrient and sediment runoff from farm fields
W. Barley - Spatial/temporal system boundaries

Counties in the DelMarVa region within 100-mi radius of Osage facility where WB can grow;

Significant Chesapeake Bay watersheds

Data sources: USDA (2010)
Biogeochemical Models

- Examination of \( N_2O \) fluxes from 10 sites in 6 states (NC, VA, KY, MD, DE, and PA) using the DAYCENT model
- Potential GHG variability/credits due to:
  - N application and timing
  - Land use history
  - Straw harvest and sale as co-product
- Allocation of \( N_2O \) fluxes in corn-winter barley-soybean 2-year rotation

P.R. Adler USDA-ARS; W. Parton, Colorado State University
Life Cycle Model

Fuel cycle

Feedstock Production

- Fertilizer
- Herbicides
- Harvesting operations
- CO2/N2O flux

Ethanol Conversion

- Chemicals, Enzymes, Nutrients
- Co-products
- Denaturant (2% gasoline)

Vehicle Operation

Vehicle use

- Blending with gasoline
- Vehicle operation

Feedstocks:
- Winter barley

Technologies:
- Dry grind process
- Sugar generation
- Fermentation
- Co-product crediting

Vehicle:
- Ethanol-fueled vehicle (E92)
- Compare with baseline
gasoline vehicle

(96 g CO2e/MJ)
Winter Barley to Ethanol

- **Inputs**: Winter Barley production, collection
- **Coproducts**: Food-grade CO₂, Onsite steam, Barley hulls, Distillers dried grains (DDGs)
- **Transport Phase**: Vehicle operation

**VT Data**: USDA, Daycent
**OSAGE Data**: Ethanol production in refinery
**GREET Data**:
LCA MODEL
Avoided Products

- Steam co-generated and recycle:
  - displacing electricity from the local grid and natural gas heat needed for steam generation.
- Fermentative CO$_2$ is captured, liquefied, and sold as a food grade CO$_2$ co-product.
- Distiller’s dried grains (DDGs)/"barley protein meal," co-produced and assumed to displace soybean meal.
- Barley hull biowaste is sold as fuel to a neighboring coal powered utility.
Emissions Calculation

- Results document the expected GHG emissions for each phase of ethanol production.
- Emissions converted into grams CO$_2$ equivalents per MJ of fuel using the global warming potential coefficients relative to CO$_2$.
  - (CO$_2$=1, CH$_4$ = 25, N$_2$O = 298)
- Avoided Products (Credits)
Feedstock Process Emissions

<table>
<thead>
<tr>
<th>GHG</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fertilizer (K20)</td>
<td>0.8</td>
</tr>
<tr>
<td>Transport</td>
<td>2.1</td>
</tr>
<tr>
<td>Fertilizer (P)</td>
<td>2.1</td>
</tr>
<tr>
<td>Traction</td>
<td>2.2</td>
</tr>
<tr>
<td>Fertilizer (N)</td>
<td>11.6</td>
</tr>
<tr>
<td>Process Emissions to Air</td>
<td>15.8</td>
</tr>
</tbody>
</table>
Refinery Process Emissions

<table>
<thead>
<tr>
<th>Category</th>
<th>Grams CO2e/MJ Ethanol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat, Coal, Avoided</td>
<td>-19.9</td>
</tr>
<tr>
<td>On Site Steam, Avoided</td>
<td>-5.9</td>
</tr>
<tr>
<td>Soy Meal, Avoided</td>
<td>-13.2</td>
</tr>
<tr>
<td>CO2, Liquid, Avoided</td>
<td>-21.8</td>
</tr>
<tr>
<td>Transport</td>
<td>1.7</td>
</tr>
<tr>
<td>Chemicals, Etc.</td>
<td>2.3</td>
</tr>
<tr>
<td>Electricity, Med Voltage</td>
<td>14.1</td>
</tr>
<tr>
<td>Heat, Natural Gas</td>
<td>35.3</td>
</tr>
</tbody>
</table>
### Net GHG Emissions Relative to Gasoline

#### Ethanol Vs Gasoline Summary

<table>
<thead>
<tr>
<th></th>
<th>Ethanol</th>
<th>Gasoline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle Operation</td>
<td>2.1</td>
<td>77</td>
</tr>
<tr>
<td>Fuel Transport</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td>Ethanol Production and Distribution</td>
<td>-7.4</td>
<td>14</td>
</tr>
<tr>
<td>Feedstock Production, Collection and Transport</td>
<td>34.7</td>
<td>6</td>
</tr>
</tbody>
</table>

**Grams CO2/MJ**

- Ethanol: 2.1 - 34.7 - 7.4
- Gasoline: 77 - 14 - 6
Parameterization

- Examination of protein co-product scenario alternatives
  - Barley hulls as fuel vs. feed
  - DDGs replaces Soybean Meal vs. Corn Meal
- Shows best scenario:
  - Hulls as fuel; DDGs replace soybean meal
- Future parameterization of:
  - Transport types/ Distances
  - Incorporate DAYCENT C/N fluxes and consideration of allocation among rotation
• **SOYBEAN/CORN** = DDGS REPLACES EITHER SOYBEAN OR CORN MEAL
• **FUEL/ FEED** = HULLS UTILIZED AS EITHER A FUEL OR A FILLER IN AGRICULTURAL FEED
Findings

- Life cycle GHG intensity of ethanol from winter barley is **30 grams CO\(_2\)e/MJ** ethanol
  - Compared to gasoline, which emits 96 grams CO\(_2\)e/MJ
  - A GHG emission reduction (~69% compared to gasoline) that would meet advanced status under RFS2
  - Important caveat: if the systems performs as modeled using single-point estimates
  - Monte Carlo Uncertainty Analysis needed:
    - Variability in N application and consequent N\(_2\)O emissions
    - Changes in co-products (e.g., CO\(_2\) bottling plant)

- On-going work is evaluating variability in the GHG intensity, especially associated with the cropping system
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