Selected Highlights of LCA Activities at NREL

LCA XIII Special Session: LCA at DOE

October 2, 2013

TEAM:
Alberta Carpenter
Garvin Heath
Daniel Inman
Margaret Mann
Ethan Warner
Yimin Zhang
Highlighted projects

1. Life cycle air pollutant emissions inventory for biofuels; spatially, temporally, and chemically explicit life cycle inventories

2. Materials Flows through Industry (MFI) tool for energy impacts

3. Land use change modeling methodology.
Comparative air pollutant emissions of selected biofuels feedstocks in 2022

Yimin Zhang, Garvin Heath, Alberta Carpenter, Noah Fisher
NREL Feedstock Production Emissions to Air Model (F-PEAM)

Inputs
- BTS (e.g., acres, yields, production by county)
- Crop Budget (e.g., fertilizer inputs, machinery usage)
- USDA Data (e.g., irrigation, types of fertilizers)
- Literature Data (e.g., emissions factors)

Linked Models
- NonRoad Model + EFs (CO, NOx, SOx, VOC, PM, NH3)
- Fertilizer Emissions (NOx, NH3)
- Pesticide Emissions (VOCs)
- Fugitive Dust (PM)

Analysis Outputs
- County-level Mass Emissions
- Emissions by Feedstock (mass per gal)
- Comparison to NEI
- Potential Impact in Nonattainment Areas

SAFETY
- Draft – Do Not Cite, Quote or Distribute
Contribution by Activity Category to County Emissions: First Step to Target Setting

Blanks represent no emissions of that pollutant for that feedstock.
Counties with Cellulosic Feedstock O₃ Precursor Emissions Exceeding 3 NEI Thresholds, Alongside Current O₃ Nonattainment Areas

<table>
<thead>
<tr>
<th>PM₂.₅</th>
<th>Number of Counties</th>
<th>1997/2006</th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>R &gt; 0.2</td>
<td>3</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>R &gt; 0.1</td>
<td>13</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>R &gt; 0.05</td>
<td>34</td>
<td>12</td>
<td></td>
</tr>
</tbody>
</table>

Counties in nonattainment for 1997 or 2006 PM₂.₅ NAAQS
Counties with concentration greater than 2012 PM₂.₅ NAAQS

Source: NREL Draft – Do Not Cite, Quote or Distribute
Counties with Cellulosic Feedstock $O_3$ Precursor Emissions Exceeding 3 NEI Thresholds, Alongside Current $O_3$ Nonattainment Areas

Source: NREL

<table>
<thead>
<tr>
<th>Ozone</th>
<th>No. Counties in Nonattainment</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R &gt; 0.2$</td>
<td>0</td>
</tr>
<tr>
<td>$R &gt; 0.1$</td>
<td>0</td>
</tr>
<tr>
<td>$R &gt; 0.05$</td>
<td>0</td>
</tr>
</tbody>
</table>

Counties in nonattainment for 1997 or 2008 8-hr Ozone NAAQS
Materials Flows through Industry (MFI) tool for energy impacts

Alberta Carpenter, Margaret Mann
What are the opportunities for manufacturing impacts across the life cycle?

- Manufacturing energy/emissions reductions
- Increased manufacturing efficiency (lower energy, faster throughput, etc.)
- New and improved processes/product.

Advanced Manufacturing

Target Technologies
- Use and re-use energy/emissions reductions (e.g., light-weighting)
- Increased value added
- Improved quality
- Etc.

Reference: "Materials & the Environment," Michael F. Ashby
Materials Flow through Industry (MFI) Tool

**Function:** A tool enables scenarios of changes in energy efficiency of processes, changes in materials use, changes in carbon intensity of materials:
- Process comparisons
- Material substitution
- Sector energy efficiency potential
- Grid mix evaluation
- Track energy & GHG emissions at the per unit (mass) product level

**Data Driven:**
- Use pre-existing lifecycle (LC) data readily adopted for parts of the sector (USLCl, ecoinvent).
- Market data and recipes for over 500 products and 1200 processes
- Recipes (mass & energy balance) of the manufacturing step: raw materials; fuel inputs; product & co-product outputs; GHG emissions (SRI).

**Output:**
- Overall material & energy balance – material flows of through supply chain.
- Energy & GHG emissions tracked at the per unit product level and at market use level.
- Tabular and graphical representation of “base case” and “scenario” (e.g. after material substitution).
MFI Tool Structure

- IO process based matrix model
- Tracks energy and fuel derived carbon emissions
- Inputs and outputs are based on LCI and process economics data (proprietary)
- Includes 500+ products, 1200+ processes
- All flows accounted for in kg or kwh.

Material Flow Matrix

Total impact of a product is equal to the cumulative impact of the commodities and intermediates that are needed to produce that product.

Source: Seungwook Ma, PhD, DOE
## Tool Inputs

### User Input Page

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 1</td>
<td>Select category</td>
<td>NONFERROUS</td>
</tr>
<tr>
<td>Step 2</td>
<td>Recalculate</td>
<td></td>
</tr>
<tr>
<td>Step 3</td>
<td>Select material</td>
<td>ALUMINUM, SMELT</td>
</tr>
<tr>
<td>Step 4</td>
<td>Recalculate</td>
<td></td>
</tr>
<tr>
<td>Step 5</td>
<td>Demand (KG)</td>
<td>1,000</td>
</tr>
<tr>
<td>Step 6</td>
<td>Steps in the supply chain</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Scenario A</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Scenario B</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Scenario C</td>
<td>5</td>
</tr>
</tbody>
</table>
## Tool Inputs

### User Input Page

**Step 1:** Select case: (Select from a list of scenarios)

**Step 2:** Recalculate: (Recalculate the results)

**Step 3:** Select material: **ALUMINUM, SMELT**

**Step 4:** Recalculate: (Recalculate with ALUMINUM, SMELT)

**Step 5:** Demand (KG): **1,000**

**Step 6:** Steps in the supply chain:

- Scenario A: 5
- Scenario B: 5
- Scenario C: 5

---

### Table of Replacement Factor

<table>
<thead>
<tr>
<th>Substitute</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALUMINUM, SMELT</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Tool Inputs

### Product: ALUMINUM, SMELT

<table>
<thead>
<tr>
<th>Process</th>
<th>Baseline Weighting</th>
<th>Equal Weighting</th>
<th>Baseline Weighting</th>
<th>Equal Weighting</th>
</tr>
</thead>
<tbody>
<tr>
<td>CARBOTHERMIC</td>
<td>0%</td>
<td>17%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>CLAY CARBOCHLORINATION</td>
<td>0%</td>
<td>17%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>HH WETTED CATHODE</td>
<td>0%</td>
<td>17%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>H-H/INERT ANODE</td>
<td>0%</td>
<td>17%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>MODERN HALL HEROUlt PROCESS</td>
<td>100%</td>
<td>17%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>SMELTING OF REFINED ALUMINA TO METALLIC ALUMINUM</td>
<td>0%</td>
<td>17%</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

### Step 4: Recalculate

**Recalculate**

### Step 5: Demand (KG):

**1,000**

### Step 6: Steps in the supply chain:

- **Scenario A**: 5
- **Scenario B**: 5
- **Scenario C**: 5

Source: NREL
## Tool Inputs

### Step 6: Steps in the supply chain:

- **Scenario A**: 5
- **Scenario B**: 5
- **Scenario C**: 5

**Product: ALUMINUM, SMELT**

<table>
<thead>
<tr>
<th>Process</th>
<th>Baseline Weighting</th>
<th>Equal Weighting</th>
<th>Input Own New Weighting Scenario A</th>
<th>Input Own New Weighting Scenario B</th>
<th>Input Own New Weighting Scenario C</th>
</tr>
</thead>
<tbody>
<tr>
<td>CARBOTHERMIC</td>
<td>0%</td>
<td>17%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>CLAY CARBOCLORINATION</td>
<td>0%</td>
<td>17%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>H-H WETTED CATHODE</td>
<td>0</td>
<td>0</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>H-H/INERT ANODE</td>
<td>0%</td>
<td>0</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>MODERN HALL HEROUIL PROCESS</td>
<td>0%</td>
<td>0</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>SMELTING OF REFINED ALUMINA TO METALLIC ALUMINUM</td>
<td>0%</td>
<td>0</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

Source: NREL
Tool Inputs

<table>
<thead>
<tr>
<th>Product: ALUMINUM, SMELT</th>
<th>Process</th>
<th>Baseline Weighting</th>
<th>Equal Weighting</th>
<th>Scenario A</th>
<th>Scenario B</th>
<th>Scenario C</th>
</tr>
</thead>
<tbody>
<tr>
<td>CARBOTHERMIC</td>
<td>0%</td>
<td>17%</td>
<td>100%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>CLAY CARBOCHLORINATION</td>
<td>0%</td>
<td>17%</td>
<td>100%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>HH WETTED CATHODE</td>
<td>0%</td>
<td>17%</td>
<td>100%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>H-H/INERT ANODE</td>
<td>0%</td>
<td>17%</td>
<td>100%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>MODERN HALL HEROUlt PROCESS</td>
<td>0%</td>
<td>17%</td>
<td>100%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>SMLETING OF RINED ALUMINA TO METALLIC ALUMINUM</td>
<td>0%</td>
<td>17%</td>
<td>100%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Product: ALUMINUM, SMELT</th>
<th>Process</th>
<th>Baseline Implementation</th>
<th>Input Own Grid Mix</th>
<th>Input Own Grid Mix</th>
<th>Input Own Grid Mix</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELECTRICITY GRID, FRCC</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>ELECTRICITY GRID, MRO</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>ELECTRICITY GRID, NATIONAL</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>ELECTRICITY GRID, NPCC</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>ELECTRICITY GRID, RFC</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>ELECTRICITY GRID, SERC</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>ELECTRICITY GRID, SPP</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>ELECTRICITY GRID, TRE</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>ELECTRICITY GRID, WECC</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

Source: NREL
Tool Outputs

- Results are still in preliminary stages
- Looking to identify which product inputs have largest energy and carbon demands.
Land use change model

Ethan Warner, Daniel Inman, Yimin Zhang
Background

Literature Review

Goal Statement

1. To create and utilize systems dynamics to model the key drivers of land use change, including biomass conversion and biofuels production.

2. To create a transparent and relatively simple model for test assumptions about land use change and to facilitate discussion about the topic area.
NREL’s Modeling Strategy & Approach

• System dynamics framework
  – Stocks/flows
  – Feedback within and across stages in supply chain.

• Modular, “regional” model architecture
  – “Region” can reflect world, nation, geographical region, level of development, etc.
  – Enables rapid extension of model from 1 → 2 → n regions.

• Reliance on demographic scenarios and FAO/GTAP data to drive dynamics around population, yield, food demand

• Calibrate model against FAO datasets for land use and disposition

• Avoidance of explicit market mechanism.
Our Model Captures Important System Interactions

Conclusions

• BioLUC modeling effort is focused on improving our understanding of how bioenergy and LUC interact
• Once complete, the model will be released publically along with processed datasets
  o To be hosted on GitHub with links; also on Bioenergy KDF
• We expect the model to facilitate much discussion among stakeholders and provide an accessible medium for groups to test different assumptions and datasets
• Having a transparent and relatively simple model (i.e., runs quickly, isn’t very large, etc.) will add value to the community as a whole
• It is our hope that model release will stimulate an “open-source” level of interest and external development.
Questions?

LUC paper citation:

Supplemental Slides
BioLUC Model Progression

Expansion from 2 to 19 regions.

Modifications to land stocks and flows based on feedback from the ORNL workshop.

Modified structure within each region.
Two-Region Insights

- Results suggest that even in a future with high food and biofuel demands there is enough “available” land to meet both food and fuel needs.
- Most of the land is supplied by “pasture”
- Demand for land-intensive meat is difficult to supply under the high biofuel scenarios

<table>
<thead>
<tr>
<th>Animal Class</th>
<th>Forage</th>
<th>Pasture</th>
<th>Maize</th>
<th>Wheat</th>
<th>Rice</th>
<th>NEC</th>
<th>Oil Crop</th>
<th>Sugar</th>
<th>Total kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cow Goat Sheep</td>
<td>6.1</td>
<td>4.9</td>
<td>2.6</td>
<td>0.1</td>
<td>0.0</td>
<td>0.0</td>
<td>1.1</td>
<td>0.0</td>
<td>14.8</td>
</tr>
<tr>
<td>Dairy</td>
<td>4.5</td>
<td>0.0</td>
<td>1.2</td>
<td>0.0</td>
<td>0.0</td>
<td>2.0</td>
<td>0.0</td>
<td>0.0</td>
<td>7.7</td>
</tr>
<tr>
<td>Pig</td>
<td>0.0</td>
<td>0.0</td>
<td>1.2</td>
<td>1.4</td>
<td>0.0</td>
<td>0.3</td>
<td>0.7</td>
<td>0.0</td>
<td>3.6</td>
</tr>
<tr>
<td>Poultry</td>
<td>0.0</td>
<td>0.0</td>
<td>1.4</td>
<td>0.3</td>
<td>0.0</td>
<td>0.0</td>
<td>0.6</td>
<td>0.0</td>
<td>2.4</td>
</tr>
</tbody>
</table>