Assessing Potential Air Pollutant Emissions from Agricultural Feedstock Production using MOVES

Annika Eberle
National Renewable Energy Laboratory

EPA’s International Emissions Inventory Conference
August 16, 2017
Billion Ton Studies

Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply
April 2005

U.S. BILLION-TON UPDATE
August 2011

2016 BILLION-TON REPORT
Advancing Domestic Resources for a Thriving Bioeconomy
Volume 2: Environmental Sustainability Effects of Select Scenarios from Volume 1
January 2017
Other contributors to Chapter 9: *Implications of air pollutant emissions from producing agricultural and forestry feedstocks* in Volume 2 of the 2016 Billion-Ton Report include:

- Ethan Warner (NREL)
- Dylan Hettinger (NREL)
- Danny Inman (NREL)
- Alberta Carpenter (NREL)
- Yimin Zhang (NREL)
- Garvin Heath (NREL)
- Arpit Bhatt (NREL)
Biofuel production may emit fewer GHG emissions than gasoline production.

Context and Study Objectives

- Biofuel production may emit fewer GHG emissions than gasoline production.
- However, the relative benefit may not hold for other air pollutants.

![Bar chart showing ammonia emissions for gasoline, corn ethanol, and cellulosic stover ethanol.](source: Tessum et al. Environ. Sci. Tech. 46 (2012) 11408-11417)
Context and Study Objectives

- Biofuel production may emit fewer GHG emissions than gasoline production
- However, the relative benefit may not hold for other air pollutants
- For some pollutants, farming activities comprise a large portion of emissions

Context and Study Objectives

• Context
  o Air pollution harms public health and environment
  o Many areas in the U.S. exceed the national air quality standards
  o Across the biomass supply chain, multiple operations emit air pollutants
  o No existing studies have yet assessed air pollutant emissions resulting from potential large-scale deployment of biomass systems
    - Developing a high-resolution emissions inventory is an essential piece of information for air quality and human health impact modeling

• The objectives of this analysis were to
  o Quantify air pollutant emissions associated with biomass production and supply logistics in order to examine
    - How emissions vary by feedstock
    - What the major emission contributors are along the biomass supply chain
    - How emissions vary spatially and may potentially impact local air quality
  o Identify opportunities to minimize potential adverse impacts
Scope of Analysis

- **Pollutants analyzed**
  - Carbon monoxide (CO), particulate matter (PM$_{2.5}$, PM$_{10}$), oxides of nitrogen (NO$_x$), oxides of sulfur (SO$_x$), volatile organic compounds (VOC), and ammonia (NH$_3$)

- **Scenarios evaluated**
  - Biomass production of corn grain
  - Biomass production and supply logistics of
    - Agricultural residues
    - Energy crops (e.g., miscanthus)
    - Whole trees
    - Logging residues

Source: www.pioneer.com; www.rhc-platform.org; www.ethanolproducer.com
Scope of Analysis

- Emission sources included
  - Combustion emissions from on-farm machinery for
    - Planting
    - Maintenance
    - Harvesting
    - On-farm transport
  - Chemical application of fertilizers and pesticides
  - Fugitive dust emissions from soil-disturbing activities
  - Combustion emissions by off-farm transportation and pre-processing
  - Drying of feedstocks (if needed)

Source: www.mississippi-crops.com; www.bls.gov; www.westargroup.com
Methods – Feedstock Production Emissions to Air Model (FPEAM)

**Inputs**
- **POLYSYS and ForSEAM inputs and outputs**
  - Biomass Production budgets, production, and harvest areas
- **Other data sources**
  - Corn grain irrigation statistics, EPA guidance and technical reports, and literature
- **SCM inputs and outputs**
  - Biomass supply logistics budgets and supply to biorefineries

**FPEAM**
- **Production activity**
  - County-level equipment use and fertilizer application
- **Supply logistics activity**
  - County-level equipment use

**Results**
- Mass emission per dry ton feedstock
- Source contributions to total emission
- County-level mass-emission density maps
- Comparison to NEI and attainment status

**Acronyms:**
- **POLYSYS** = Policy Analysis System
- **ForSEAM** = Forest Sustainable and Economic Analysis Model
- **SCM** = Supply Characterization Model
- **MOVES** = MOtor Vehicle Emission Simulator
- **NEI** = National Emissions Inventory
Methods – Executing NONROAD and MOVES

Executed at county level using county-level equipment populations

Create Database

Setup NONROAD

Run NONROAD

Save Data

Run MOVES

Save Data

Post-Process Results

Executed in Rates mode for representative counties
Methods – Executing NONROAD and MOVES

- Generate population files
- Create allocation and option files
- Execute batch runs
- Extract inventory data from text files
Methods – Executing NONROAD and MOVES

- Create Database
  - Setup NONROAD
    - Run NONROAD
    - Save Data
  - Setup MOVES
    - Run MOVES
    - Save Data

- Post-Process Results

- Generate input data files
- Create XML file for data import
- Create XML file for MOVES run
- Execute batch runs (locally or via AWS)
- Post-process MOVES data to calculate emissions
FPEAM Results – Emissions from Production by Feedstock

Emissions (lb/dt)

- NH₃
- NOₓ
- PM₂.₅
- PM₁₀
- CO
- SOₓ
- VOC

Feedstock:

- CG
- SR
- SW
- SG
- MS
- LR
- TB

Counts:

- CG: 657, 2,633, 1,138, 1,295, 1,711, 1,711, 1,790, 2,633
FPEAM Results – Emissions from Production by Feedstock

CG = corn grain
SR = stover
SW = straw
SG = switchgrass
MS = miscanthus
LR = logging residue
TB = whole-tree biomass
lb = pound
dt = dry ton
n = # of feedstock producing counties
FPEAM Results – Emissions from Production by Feedstock

CG = corn grain
SR = stover
SW = straw
SG = switchgrass
MS = miscanthus
LR = logging residue
TB = whole-tree biomass
lb = pound
dt = dry ton
n = # of feedstock producing counties
FPEAM Results – Emissions from Production and Supply Logistics

SR = stover
SG = switchgrass
MS = miscanthus
LR = logging residue
TB = whole-tree biomass
lb = pounds
dt = dry ton
n = # of counties
producing and supplying feedstock
**FPEAM Results — Emissions from Production and Supply Logistics**

- SR = stover
- SG = switchgrass
- MS = miscanthus
- LR = logging residue
- TB = whole-tree biomass

<table>
<thead>
<tr>
<th>Emissions (lb/dt)</th>
<th>SR</th>
<th>SG</th>
<th>MS</th>
<th>LR</th>
<th>TB</th>
</tr>
</thead>
<tbody>
<tr>
<td>NH₃</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(n)</td>
<td>574</td>
<td>1,034</td>
<td>1,407</td>
<td>1,571</td>
<td>210</td>
</tr>
</tbody>
</table>

lb = pounds
dt = dry ton
n = # of counties
producing and supplying feedstock
Results – Emissions Contribution by Source

SR = stover; SG = switchgrass; MS = miscanthus; LR = logging residue; TB = whole-tree biomass
FPEAM Results – National Emissions Inventory (NEI) Ozone Emission Ratio

2017

Emission Ratio for Ozone Precursor Emissions (%)

- 9 - 10
- 6 - 9
- 3 - 6
- 1 - 3
- 0 - 1
- No biomass production

2015 Ozone Attainment Status

- Non-Attainment
FPEAM Results – National Emissions Inventory (NEI) Ozone Emission Ratio

2040

Emission Ratio for Ozone Precursor Emissions (%)
- 9 - 10
- 6 - 9
- 3 - 6
- 1 - 3
- 0 - 1
- No biomass production

2015 Ozone Attainment Status
- Non-Attainment
Key Findings

- **Air emissions vary by feedstock** (per dry ton [dt] of biomass produced or supplied)
  - Cellulosic feedstocks fare better than corn grain for most air pollutants

- **Potential air quality implications**
  - Future air pollutant emissions, if realized and additional, could pose challenges for local compliance with air quality regulations

- **Potential emission reductions**
  - Could be achieved through landscape management or technology improvements
Conclusions and Recommendations

• Several important data and methods limitations in our modeling require future research and development, including
  - Biogenic emissions attributed to biomass growth, harvest and preprocessing
  - Upstream emissions (e.g., fertilizer manufacturing)
  - Fugitive dust emissions from forestry activities

• Emission estimates do NOT model changes in emissions relative to a reference “business as usual” (BAU) scenario
  - A BAU scenario was not available for the 2016 Billion-Ton Report
  - The air emissions inventory was developed to understand potential implications
  - Full air quality and human health impact modeling would require a BAU scenario

• Emission estimates from this study could
  - Inform long-range air quality planning, such as state implementation plans, which are required to consider new emission sources for future scenarios
  - Be coupled with air-quality screening tools to evaluate important changes in emission concentrations and potential impacts on human health
Acknowledgements

This project was supported by the U.S. Department of Energy’s Bioenergy Technologies Office under Contract No. DE-AC36-08-GO28308.

Other contributors to Chapter 9: *Implications of air pollutant emissions from producing agricultural and forestry feedstocks* in Volume 2 of the 2016 Billion-Ton Report include:

- Ethan Warner (NREL)
- Dylan Hettinger (NREL)
- Danny Inman (NREL)
- Alberta Carpenter (NREL)
- Yimin Zhang (NREL)
- Garvin Heath (NREL)
- Arpit Bhatt (NREL)

Many thanks to EPA MOVES support staff, Laurence Eaton (Oak Ridge National Laboratory), Erin Searcy and Damon Hartley (Idaho National Laboratory), Jennifer Dunn and Christina Canter (Argonne National Laboratory), Patrick Gaffney and Janet Spencer (California Air Resources Board), Maureen Puettmann (Consortium for Research on Renewable Industrial Materials), Craig Brandt and Erin Webb (Oak Ridge National Laboratory), and Bryce Stokes (Allegheny Science & Technology).
### Details on Methods

<table>
<thead>
<tr>
<th>Purpose</th>
<th>FPEAM Modeling Method</th>
<th>Emission Species</th>
<th>Spatial Resolution</th>
<th>Estimation Methods/Data Sources</th>
<th>Details in Appendix Section</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Annual Equipment Usage and Chemical Application</strong></td>
<td>Equipment and Chemical Application Budgets&lt;sup&gt;a&lt;/sup&gt;</td>
<td>CO, NO&lt;sub&gt;x&lt;/sub&gt;, SO&lt;sub&gt;x&lt;/sub&gt;, PM&lt;sub&gt;2.5&lt;/sub&gt;, PM&lt;sub&gt;10&lt;/sub&gt;, VOCs, NH&lt;sub&gt;3&lt;/sub&gt;</td>
<td>Agriculture: 13 regional budgets&lt;br&gt;Forestry: 5 regional budgets&lt;br&gt;Supply Logistics: National&lt;br&gt;Corn Grain Irrigation: State</td>
<td>POLYSYS, ForSEAM, and SCM modeling inputs (DOE 2016)&lt;br&gt;Corn Grain Irrigation: USDA (2009)</td>
<td>9.6.1.1</td>
</tr>
<tr>
<td></td>
<td>Harvest Area and Biomass Production</td>
<td>CO, NO&lt;sub&gt;x&lt;/sub&gt;, SO&lt;sub&gt;x&lt;/sub&gt;, PM&lt;sub&gt;2.5&lt;/sub&gt;, PM&lt;sub&gt;10&lt;/sub&gt;, VOCs, NH&lt;sub&gt;3&lt;/sub&gt;</td>
<td>County</td>
<td>POLYSYS, ForSEAM, and SCM modeling estimates (DOE 2016)</td>
<td>9.6.1.1</td>
</tr>
<tr>
<td><strong>EFs For Estimating Annual Emissions</strong></td>
<td>Off-Road Fuel Use</td>
<td>CO, NO&lt;sub&gt;x&lt;/sub&gt;, SO&lt;sub&gt;x&lt;/sub&gt;, PM&lt;sub&gt;2.5&lt;/sub&gt;, PM&lt;sub&gt;10&lt;/sub&gt;, VOCs, NH&lt;sub&gt;3&lt;/sub&gt;</td>
<td>State EFs</td>
<td>NONROAD (EPA 2016b)</td>
<td>9.6.1.2.1</td>
</tr>
<tr>
<td></td>
<td>On-Road Fuel Use</td>
<td>CO, NO&lt;sub&gt;x&lt;/sub&gt;, SO&lt;sub&gt;x&lt;/sub&gt;, PM&lt;sub&gt;2.5&lt;/sub&gt;, PM&lt;sub&gt;10&lt;/sub&gt;, VOCs, NH&lt;sub&gt;3&lt;/sub&gt;</td>
<td>State EFs</td>
<td>MOVES (EPA 2016a)</td>
<td>9.6.1.2.2</td>
</tr>
<tr>
<td></td>
<td>Preprocessing Fuel Use</td>
<td>CO, NO&lt;sub&gt;x&lt;/sub&gt;, SO&lt;sub&gt;x&lt;/sub&gt;, PM&lt;sub&gt;2.5&lt;/sub&gt;, PM&lt;sub&gt;10&lt;/sub&gt;, VOCs, NH&lt;sub&gt;3&lt;/sub&gt;</td>
<td>State EFs</td>
<td>NONROAD (EPA 2016b)</td>
<td>9.6.1.2.3</td>
</tr>
<tr>
<td></td>
<td>Chemical Application</td>
<td>NO&lt;sub&gt;x&lt;/sub&gt;, VOCs</td>
<td>National EFs</td>
<td>EPA (2015d)&lt;br&gt;ANL 2015&lt;br&gt;USDA (2010)&lt;br&gt;Davidson et al. 2004&lt;br&gt;Huntley (2012)</td>
<td>9.6.1.2.4</td>
</tr>
<tr>
<td></td>
<td>Fugitive Dust</td>
<td>PM&lt;sub&gt;2.5&lt;/sub&gt; and PM&lt;sub&gt;10&lt;/sub&gt;</td>
<td>EFs based on a combination of state and national data</td>
<td>Agriculture Harvest and Non-Harvest: CARB (2003), Gaffney and Yu (2003)&lt;br&gt;Forestry: No methodology or data could be found&lt;br&gt;Transportation: EPA (2006)&lt;br&gt;Preprocessing: None due to dust-collection equipment (INL 2013, INL 2014)</td>
<td>9.6.1.2.5</td>
</tr>
<tr>
<td></td>
<td>Drying and Preprocessing</td>
<td>VOCs</td>
<td>National EFs</td>
<td>Herbaceous: Assumed to be zero&lt;br&gt;Woody: EPA (2002)</td>
<td>9.6.1.2.6</td>
</tr>
</tbody>
</table>
SR = stover
SG = switchgrass
MS = miscanthus
LR = logging residue
TB = whole-tree biomass
lb = pounds
dt = dry ton
n = # of counties producing and supplying feedstock
## Methods – Scope

**Pollutants analyzed**
- carbon monoxide (CO), particulate matter (PM$_{2.5}$, PM$_{10}$), oxides of nitrogen (NO$_x$), oxides of sulfur (SO$_x$), volatile organic compounds (VOC), and ammonia (NH$_3$)

**Scenarios evaluated**

<table>
<thead>
<tr>
<th>Feedstock type</th>
<th>Segment of supply chain</th>
<th>BCI&amp;ML$^a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn grain</td>
<td>Biomass production</td>
<td>$\text{Up to }$60/dt</td>
</tr>
<tr>
<td>Agricultural residues, energy crops, whole tree biomass and logging residues</td>
<td>Biomass production</td>
<td>$\text{Up to }$60/dt</td>
</tr>
<tr>
<td></td>
<td>Biomass supply logistics – near term</td>
<td>$\text{Up to }$100/dt</td>
</tr>
<tr>
<td></td>
<td>Biomass supply logistics – long term</td>
<td>Not modeled</td>
</tr>
</tbody>
</table>

### Emission sources included
1. Fuel use by on-farm machinery operation, harvesting, and on-farm transportation
2. Fuel use by off-farm transportation and biomass preprocessing
3. Chemical application of fertilizers and pesticides
4. Fugitive dust emissions from soil-disturbing activities (e.g., land preparation, harvesting, transportation)
5. Drying of feedstocks (if needed)

---

$^a$ BCI=agricultural base case yield growth, ML = moderate housing and low wood energy

$^b$ Includes cost to produce and supply biomass
FPEAM Results – National Emissions Inventory (NEI) Emission PM$_{2.5}$ Ratio

2017