Economics and Greenhouse Gases
Emissions of a Biofuel Supply Chain in Tennessee

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Feedstock for Advanced Biofuels

- Lignocellulosic biomass (LCB) energy crops, such as switchgrass, have high potentials in meeting the national mandate of advanced biofuels in the EISA 2007
- Switchgrass has higher biomass content, less inputs use, and less linkage to food prices when compared to conventional crop feedstocks
- However, low bulk density relative to energy content of switchgrass is currently an issue in its biofuel supply chains (BSC)
Design of Biofuel Supply Chains

• Configurations in a cellulosic BSC include
  – Upstream: feedstock production, collection, preprocessing, storage and transportation
  – Midstream: biofuel conversion
  – Downstream: biofuel transportation

• Most of current BSC studies in the literature
  – Applied GIS model for spatial analysis without optimization in decision process
  – Utilized mathematical programming model for system optimization without a fine resolution data to illustrate and validate
Geospatial Elements of Biofuel Supply Chain

• Regional attributes that may affect the optimal configuration of the supply chains include:
  – 1) available land resources for growing feedstock in relation to the biofuel end-user market,
  – 2) the opportunity costs of converting agricultural land to switchgrass production,
  – 3) available infrastructure for placement of the conversion facility, and
  – 4) the real road network for movement of feedstock and biofuel products
Research Objectives

• Estimate the impact of switchgrass harvest & storage configurations on the economic (NPV) and environmental (GHG emissions) outcome of the BSC.

• Illustrate the impact of different objectives (NPV max vs. GHG min) on the decision of the placement of switchgrass BSC
Overview of the Model for NPV Maximization

**Inputs**
- Feedstock (switchgrass):
  - simulated yield;
  - available land;
  - total establishment cost;
  - annual production, harvest, storage cost.
- Transportation:
  - total capital investment cost;
  - annual transportation cost (labor, fuel, equipment).
- Preprocessing:
  - total capital investment cost;
  - annual operation cost (labor, energy, equipment).
- Conversion:
  - total capital investment cost;
  - annual conversion cost (labor, energy, equipment).
- Biofuel market:
  - annual demand quantity;
  - biofuel price.

**Outputs**
- Location and capacity of conversion and preprocessing facilities
- Feedstock draw area & land use change
- Feedstock management (harvest, shipment and storage)
- Biofuel management (production and shipment)
- Annual biofuel supply chain cost by component
- Annual revenue & NPV of profit

**GHG emissions**
- Land use change (DayCent model)
- Feedstock production, harvest, storage and preprocessing (GREET database)
- Biofuel production (GREET and NREL database)
- Feedstock and biofuel transportation (MOVES model)
Mixed-Integer Optimization Model

- **Objective function for maximizing NPV:**

  \[
  \text{NPV} = (1+r)^{-T} (\text{TR} - \text{TC} + \text{Sal})
  \]

  \[
  \text{TR} = \left( \sum_j \sum_g \sum_m \text{Bio}^{fac}_{jg} (p^{bio} \times Y^{bio}_{jgm} + p^{co} \times Y^{co}_{jgm}) \right)
  \]

  \[
  \text{TC} = C^{swi}_{est} + C^{swi}_{pm} + C^{swi}_{sm} + C^{swi}_{hm} + C^{bio}_{om} + C^{bio}_{hm} + C^{bio}_{inv}
  \]

  \[
  C^{swi}_{pm} = (\sum_i \sum_l \text{BEP}_{il} \times X_{il})
  \]

  \[
  \text{BEP}_{il} = \begin{cases}
  \frac{(\text{Price}_{il} \times \text{Yield}_{il} - P_{il}) + \gamma_i + \theta_i}{\text{Yield}_{i}^{swi}}, & \text{if } (\text{Price}_{il} \times \text{Yield}_{il} - P_{il}) \geq L_{Ril} \\
  \frac{L_{Ril} + \gamma_i + \theta_i}{\text{Yield}_{i}^{swi}}, & \text{if } ((\text{Price}_{il} \times \text{Yield}_{il} - P_{il}) < L_{Ril}
  \end{cases}
  \]
Study Assumptions

• Biofuel production target: 20% of transportation fuel used in TN in 2011 (~1.0 billion gallons per year)
  – Demand in west TN is based on the share of regional population (28%)
• Max NPV of two harvest/storage systems:
  – large square balers (LSB) & chopping & wrap round baler (CWR)
• Single harvest season (Nov-Feb): storage dry matter losses of feedstock considered
• No more than 50% of total hay and pasture land can be converted for switchgrass
Data

• Simulated switchgrass yield: Jager et al. (2010)
• Price of crops: average of 2011-13 (USDA NASS)
• Production cost of corps: USDA and POLYSYS
• Production and harvest of switchgrass: Larson et al. (2010) and UT Extension
• Dry matter loss: Mooney et al. (2012)
• Soil carbon estimation: DayCent (Schimel et al. 2001)
• Energy consumption emission: GREET model (Argonne)
• Transportation emission/pollutants: MOVES (US EPA)
Optimal Placement of LSB System
Optimal Placement of CWR System
## Economic Output of LSB & CWR Systems

<table>
<thead>
<tr>
<th>Category</th>
<th>LSB</th>
<th>CWR</th>
</tr>
</thead>
<tbody>
<tr>
<td>total annual revenue</td>
<td>1,247.4</td>
<td>1,247.4</td>
</tr>
<tr>
<td>annual feedstock opportunity costs</td>
<td>4.3</td>
<td>4.6</td>
</tr>
<tr>
<td>annual feedstock maintenance cost</td>
<td>21.2</td>
<td>21.5</td>
</tr>
<tr>
<td>annual feedstock harvest &amp; storage cost</td>
<td>137.0</td>
<td>--</td>
</tr>
<tr>
<td>annual feedstock preprocessing &amp; storage cost</td>
<td>--</td>
<td>45.8</td>
</tr>
<tr>
<td>annual feedstock transportation cost</td>
<td>66.9</td>
<td>99.6</td>
</tr>
<tr>
<td>annual feedstock grinding cost</td>
<td>78.9</td>
<td>46.7</td>
</tr>
<tr>
<td>annual biofuel production costs</td>
<td>362.1</td>
<td>362.1</td>
</tr>
<tr>
<td>annual biofuel transportation cost</td>
<td>18.9</td>
<td>16.5</td>
</tr>
<tr>
<td>total annual cost</td>
<td>689.3</td>
<td>618.4</td>
</tr>
<tr>
<td>feedstock establishment cost (years 0 &amp; 10)</td>
<td>192.1</td>
<td>194.9</td>
</tr>
<tr>
<td>preprocessing facility investment cost (year 0)</td>
<td>--</td>
<td>75.8</td>
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<tr>
<td>preprocessing facility salvage at year 20</td>
<td>--</td>
<td>8.0</td>
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<tr>
<td>conversion facility investment cost (year 0)</td>
<td>2,037.8</td>
<td>2,037.8</td>
</tr>
<tr>
<td>conversion facility salvage at year 20</td>
<td>213.4</td>
<td>213.4</td>
</tr>
<tr>
<td>NPV over 20 years</td>
<td>1,276.1</td>
<td>1,642.2</td>
</tr>
</tbody>
</table>
## GHG Emissions and Air Pollutant in LSB & CWR

<table>
<thead>
<tr>
<th>Description</th>
<th>Unit</th>
<th>LSB</th>
<th>CWR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average GHG emissions from all components in BSC</td>
<td>CO2e g/gallon</td>
<td>2,166.21</td>
<td>2,222.80</td>
</tr>
<tr>
<td>Average GHG emissions from transportation in BSC</td>
<td>CO2e g/gallon</td>
<td>116.65</td>
<td>211.08</td>
</tr>
<tr>
<td>Average NO$_x$ emissions from transportation in BSC</td>
<td>g/gallon</td>
<td>1.69</td>
<td>1.90</td>
</tr>
<tr>
<td>Average PM$_{2.5}$ emissions from transportation in BSC</td>
<td>g/gallon</td>
<td>0.04</td>
<td>0.08</td>
</tr>
<tr>
<td>Average PM$_{10}$ emissions from transportation in BSC</td>
<td>g/gallon</td>
<td>0.04</td>
<td>0.08</td>
</tr>
</tbody>
</table>
Maps of NPV Max and GHG Min for LSB

Square BSC: NPV max

Square BSC: GHG min
## NPV of Cash Flows under Two Objectives in LSB

<table>
<thead>
<tr>
<th>Description</th>
<th>NPV Max</th>
<th>GHG Min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual sales revenue from biofuel</td>
<td>1,218,134,438</td>
<td>1,218,134,438</td>
</tr>
<tr>
<td>Annual byproducts from conversion facilities</td>
<td>29,233,268</td>
<td>29,233,268</td>
</tr>
<tr>
<td>Annual switchgrass opportunity cost</td>
<td>4,341,463</td>
<td><strong>119,176,284</strong></td>
</tr>
<tr>
<td>Annual maintainence cost</td>
<td>21,188,023</td>
<td>20,951,959</td>
</tr>
<tr>
<td>Annual harvest cost</td>
<td>122,838,923</td>
<td>122,637,608</td>
</tr>
<tr>
<td>Annual storage cost</td>
<td>14,189,271</td>
<td>14,189,271</td>
</tr>
<tr>
<td>Annual switchgrass transportation cost</td>
<td>66,886,666</td>
<td>60,479,279</td>
</tr>
<tr>
<td>Annual biofuel transportation cost</td>
<td>18,904,124</td>
<td>18,719,435</td>
</tr>
<tr>
<td>Annual biofuel conversion &amp; grinding cost</td>
<td>440,974,507</td>
<td>440,974,507</td>
</tr>
<tr>
<td>Switchgrass establishment cost at years 0 &amp; 10</td>
<td>192,118,612</td>
<td>189,978,147</td>
</tr>
<tr>
<td>Conversion facilities investment cost at year 0</td>
<td>2,037,782,797</td>
<td>2,194,790,167</td>
</tr>
<tr>
<td>Conversion facilities salvage value at year 20</td>
<td>213,353,298</td>
<td>229,791,773</td>
</tr>
<tr>
<td><strong>NPV of profit over 20 years</strong></td>
<td><strong>1,276,121,471</strong></td>
<td><strong>447,469,440</strong></td>
</tr>
</tbody>
</table>
GHG Emissions of NPV Max & GHG Min in Square Bale

- Biofuel transportation
- Feedstock transportation
- Feedstock maintenance
- Feedstock storage
- Feedstock harvest
- Land coverage change
Land Coverage Change to Switchgrass

NPV max

GHG min

- Corn
- Cotton
- Sorghum
- Hay & Pasture
- Rice
- Soybeans
- Wheat
Relationship of Carbon and Cost from Land Coverage Change

<table>
<thead>
<tr>
<th>Land Use Change</th>
<th>Soil carbon emissions</th>
<th>Opportunity cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cropland → switchgrass</td>
<td>Decrease</td>
<td>High</td>
</tr>
<tr>
<td>Hay &amp; pasture land → switchgrass</td>
<td>Increase</td>
<td>Low</td>
</tr>
</tbody>
</table>
Tradeoff Curve of NPV and GHG Emissions

NPV over 20 years (Millions $)

Annual GHG Emissions CO2equiv (Millions Kg)
Land Coverage Change under NPV Max
Feedstock Area and Biofuel Flows
Land Coverage Change under GHG Min
Conclusions

• System configurations have important implications to the economic and environmental outcome of the BSC.
• Preprocessing system with chopping and strach-wrap baler has higher NPV but emits more GHG compared to traditional large square baler system.
• The type of agricultural land converted to biomass feedstock production is very influential to both economic and environmental outcome in BSC.
• High-resolution geospatial data provides better insight the optimal placement of BSC.
Thanks!
Comments and Questions?

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