1.2.3.1
Feedstock Supply Modeling

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Feedstocks Supply and Logistics

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Goal Statement

Build and apply simulations of biomass supply chains
Expanding biomass availability and cost projections to the reactor throat

Harvest, storage, handling, & preprocessing
- Spatial distribution of feedstocks
- Weather data
- Machine performance data
- Purchase prices

Spatial analysis of transportation and use
- Logistics costs
- Overcontracting buffer
- Losses
- Roadside quantity and cost

IBSAL
- Costs
- Energy input
- CO₂ from fuel
- Resources required

Supply Characterization Model
- Transport Distances
- Transport costs
- Reactor throat cost
Quad Chart Overview

Timeline
• 10/1/2015
• 9/30/18
• 60%

Barriers
• Ft-A Feedstock Availability and Cost
• Ft-L Biomass Handling and Transport
• Ft-M Overall Integration and Scale-Up

Budget

<table>
<thead>
<tr>
<th>FY 15 Costs</th>
<th>FY 16 Costs</th>
<th>Total Planned Funding (FY 17-Project End Date)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOE Funded</td>
<td>$760K</td>
<td>$1,050K</td>
</tr>
</tbody>
</table>

Collaborations
• Idaho National Laboratory
• University of British Columbia
• University of Tennessee
• Virginia Tech
• University of Texas at San Antonio
1 - Project Overview

Simulation analyses of biomass supply chains

IBSAL Algae: Feasibility assessment of pelletizing algae biomass

Regional feasibility of field drying stover

Equipment to utilize available corn stover

Validation of logistics demonstration projects

Spatial analysis to estimate delivered costs for BT16

Assessing industrial relevance of feedstock combinations
Addressing project challenges

- **Integrity of simulations**
  - Assemble a diverse, multi-disciplinary team to avoid bias

- **Relevance**
  - Consistent communication with industry partners to maintain awareness of challenges encountered in industry development

- **Simulation accuracy**
  - Rigorous model verification and validation
2 – Approach (Technical)

**Integrated Biomass Supply and Logistics Model (IBSAL)**

- **Supply Characterization Model (SCM)**
  - Site utilization facilities to minimize delivered feedstock cost
  - Estimate distance, cost to move biomass from source to destination

- **Interactive Data Visualizations**
  - Results are large, complex datasets
  - Interactive visualization useful in quality control and analysis

- **Transportation and spatial analysis**
  - Potential facility locations limited to a 50-mi grid snapped to nearest highway network node

- **Costs, throughput by operation**
  - Transportation distance and cost
  - Total cost

A discrete-event modeling platform that includes:
- Lost time due to weather
- Field drying of herbaceous biomass
- Tracking biomass moisture
- Stochastic inputs

Potential biorefinery site

Explore results at county-scale, Dissemination of results

Potential facility locations limited to a 50-mi grid snapped to nearest highway network node

Counties and preprocessing depots supplying selected biorefinery
3 – Technical Accomplishments/ Progress/Results

IBSAL Algae: Feasibility assessment of pelletizing algae biomass

- Achieving the BETO cost goal of $3/GGE for algae-derived biofuel requires improvements in supply chain efficiency
- Pelletization also promising for:
  - Using algae biomass as a blendstock
  - Using algae residuals
  - Increase storability to provide buffer in case of pond crash and time of low yields

<table>
<thead>
<tr>
<th></th>
<th>Lipid Extraction</th>
<th>Hydrothermal Liquefaction</th>
<th>Pellet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feedstock production to 20% solids</td>
<td>$543</td>
<td>$761</td>
<td>$543</td>
</tr>
<tr>
<td>Conversion cost</td>
<td>$156</td>
<td>$102</td>
<td>$43</td>
</tr>
<tr>
<td>Storage</td>
<td>$2.77</td>
<td>$2.77</td>
<td>$2.50</td>
</tr>
<tr>
<td>Transport by truck (100 km)</td>
<td>$13</td>
<td>$13</td>
<td>$19</td>
</tr>
<tr>
<td>TOTAL</td>
<td>$714</td>
<td>$878</td>
<td>$608</td>
</tr>
</tbody>
</table>

Using the IBSAL-algae model, an alternative supply chain option to dry and densify algae biomass was shown to be potentially viable.
3 – Technical Accomplishments/ Progress/Results
Regional feasibility of field drying corn stover

- Initial moisture: 53%
- Harvest timing based on USDA data for corn harvest progress, by state
- Typical year weather data
- Stover wetting/drying model from Manstretta and Rossi (2015)

Field drying is a challenge in many corn-producing regions.
- High-moisture harvest, storage strategies needed
- Cost estimates in resource assessments should account for moisture challenges
3 – Technical Accomplishments/ Progress/Results

Equipment required to utilize available corn stover

We considered 17 major corn-growing states
~108 million dry tons of corn stover
272 ethanol plants producing 25 million gal/year
Total of 6.8 billion gal/year

<table>
<thead>
<tr>
<th>Logistics equipment</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stover chopper</td>
<td>44,858</td>
</tr>
<tr>
<td>Baler</td>
<td>36,702</td>
</tr>
<tr>
<td>Bale collector/stacker</td>
<td>37,517</td>
</tr>
<tr>
<td>Tractors (185-220hp)</td>
<td>66,878</td>
</tr>
<tr>
<td>Telescopic loader</td>
<td>12,233</td>
</tr>
<tr>
<td>Semi-trailer truck</td>
<td>20,390</td>
</tr>
<tr>
<td>53ft flatbed trailer</td>
<td>20,390</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>238,968</strong></td>
</tr>
</tbody>
</table>

Total economic value = $30 billion

Ebadian, M., S. Sokhansanj, and E. Webb. 2017. Estimating the required logistical resources to support the development of a sustainable corn stover bioeconomy in the USA. *Biofuels, Bioproducts, and Biorefining (Biofpr)* 11:129-149.
Number of intermediate storage sites: **1,903**
Total land area to store bales after harvest: **35,320 acres**
Total stover post harvest inventory: **53.1 million dry tons**
Estimated value of storage area: **$8.8 million**

In FY17 this work moved to new CEMAC project (6.3.0.9)
3 – Technical Accomplishments/ Progress/Results

Number of logistics operators

<table>
<thead>
<tr>
<th>Type of workforce</th>
<th>Number of workers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equipment operators</td>
<td>49,208</td>
</tr>
<tr>
<td>Storage operators</td>
<td>1,359</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>50,567</strong></td>
</tr>
</tbody>
</table>

In FY17 this work moved to new CEMAC project (6.3.0.9)

![Graph showing the number of logistics operators in different states](image)
**DATA SOURCES**

**Roadside costs and quantities**
- From BT16
  - By county, by feedstock
  - Supplies ≤$60/dry ton
  - Located at county centroid
  - Base case and high-yield scenario

**Logistics costs**
- From 2017 Logistics Design Cases (INL, 2013)

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**FEEDSTOCKS**

**Herbaceous**
- Biochemical Pathway
  - Biomass sorghum
  - Corn stover
  - Miscanthus
  - Switchgrass
  - Yard trimmings

**Woody**
- Thermochemical Pathway
  - Residues
  - Whole tree
  - C&D wastes
  - Urban wood wastes
  - Woody energy crops
Roadside availability at ≤ $60/dry ton in 2022

Feedstocks in Delivered Scenario Analysis

- Miscanthus
- Switchgrass
- Corn stover
- Poplar
- Willow
- Whole trees
- Biomass sorghum
- CD waste
- Forest residues
- MSW wood
- Yard trimmings
- Eucalyptus

Cost ($/ton) vs. Delivered quantity (tons/year) vs. Dry tons per year (in millions)

- 2022, base case
- 2040, base case
- 2040, high yield
Delivered costs of select feedstocks in 2022

Cost target: $84/dry ton

- Near term roadside
- Near term delivered (marginal)
- Near term delivered (average)
3 – Technical Accomplishments/ Progress/Results
BT16 Chapter 6: To the Biorefinery

Roadside availability at ≤ $60/dry ton in 2040

- Near term roadside
- Near term delivered (marginal)
- Near term delivered (average)
- Long term roadside, base case

Cost ($/ton) vs. Delivered quantity (tons/year)

- $0 to $120 on the y-axis
- 0 to 1,000 millions on the x-axis
Delivered costs of select feedstocks in 2022 and 2040

Cost target: $84/dry ton
Roadside availability at ≤ $60/dry ton in 2040 [High-yield scenario]

Annual yield improvements
Base case: 1%
High-yield: 3%
Delivered costs of select feedstocks in 2022 and 2040

Cost target: $84/dry ton
3 – Technical Accomplishments/ Progress/Results
BT16 Chapter 6: To the Biorefinery

Interactive version available at: https://bioenergykdf.net/billionton2016/6/2/tableau

Scenarios available:
• Herbaceous vs. Woody feedstocks
• Near-term (2022) vs Long-term (2040)
• Base case yield vs. High-yield

Quantity used by cost, by feedstock

Cost breakdown: transportation, logistics, and production

Quantity and average cost by county
3 – Technical Accomplishments/ Progress/Results

Assessing industrial relevance of feedstock combinations

Utilizing multiple feedstocks is an important strategy for reducing costs and mitigating supply risk and variability.

- What are the most likely feedstock combinations?
- Where are multi-feedstock strategies most likely?

### Assumptions
- Approach similar to BT16 using SCM model
- Conventional supply chain design
- Biorefinery can accept any feedstock combination

### Biochemical Scenario (herbaceous feedstocks)

<table>
<thead>
<tr>
<th>Year</th>
<th>Total Biorefineries</th>
<th>% Single feedstock</th>
<th>% Multiple feedstock</th>
</tr>
</thead>
<tbody>
<tr>
<td>2017</td>
<td>73</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>2022</td>
<td>220</td>
<td>31</td>
<td>69</td>
</tr>
<tr>
<td>2025</td>
<td>277</td>
<td>35</td>
<td>65</td>
</tr>
<tr>
<td>2030</td>
<td>323</td>
<td>42</td>
<td>58</td>
</tr>
</tbody>
</table>

**NOTE:** Here multiple feedstocks could be blends, different receiving/processing lines, or seasonal use.

Multiple-feedstock biorefineries particularly important as energy crop production expands.
3 – Technical Accomplishments/ Progress/Results
Assessing industrial relevance of feedstock combinations

Thermochemical Scenario (woody feedstocks)

<table>
<thead>
<tr>
<th>Year</th>
<th>2017</th>
<th>2022</th>
<th>2025</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Biorefineries</td>
<td>117</td>
<td>126</td>
<td>129</td>
<td>168</td>
</tr>
<tr>
<td>% Single feedstock</td>
<td>72</td>
<td>61</td>
<td>60</td>
<td>42</td>
</tr>
<tr>
<td>% Multiple feedstock</td>
<td>28</td>
<td>39</td>
<td>40</td>
<td>58</td>
</tr>
</tbody>
</table>

Legend:
- Other
- Tree + Residue + Coppice
- Tree + NonCoppice
- Coppice + Noncoppice
- Tree + Coppice
- Tree + Residue
- Residue
- Tree
4 – Relevance

• COST AND QUANTITY
  – IBSAL Algae modeling analysis suggests that pelletizing algae has potential to reduce supply chain costs
  – Stover field drying analysis enables us to account for moisture-management in future resource assessment cost projections
  – New delivered cost analysis for BT16 makes it possible to move beyond case study cost analysis only and to evaluate BETO cost targets at a national scale
  – Spatial analysis of biomass supplies used to determine where using multiple feedstocks reduces biorefinery cost

• QUALITY
  – New stover field drying analysis improves accuracy of moisture tracking in IBSAL corn stover models
  – Spatial analysis of biomass supplies identifies promising candidate feedstock blends for experimental testing

• INDUSTRY IMPACTS
  – Corn stover bioeconomy has near-term potential to add $30 billion to ag harvest and transport equipment industries
5 – Future Work

• Modeling biomass moisture management
  – Expand field drying analysis to other herbaceous feedstocks
  – Model stover ensilage supply chains (collaboration with INL)
  – Develop regional harvest costs for resource assessment modeling

• Equipment, infrastructure for bioeconomy
  – In FY17 this work moved to NEW project with Clean Energy Manufacturing Analysis Center (CEMAC) at NREL with INL
  – Evaluate new feedstocks, new supply systems

• Spatial analysis of biomass delivery
  – Expand and refine modeling to better represent biorefinery decisions
  – Explore feedback loop between industry expansion and biomass crop adoption
  – Add model constraints to achieve prescribed feedstock blends and test industrial relevance of promising blends
5 – Future Work

• Modeling operational disruptions
  – Build model to compare cost impacts of problematic bale-handling operations at a biorefinery vs. at an advanced preprocessing depot
  – Operational challenges to consider
    • Disruptions due to feedstock handling issues
    • Risk of fire in large biomass bale yards

• Modeling supply variability
  – Apply IBSAL and SCM to quantify benefits of commoditized feedstocks in reducing impacts of supply variability
    • Hypothesis: Biorefineries will be willing to pay higher average feedstock costs for a more reliable supply
    • Cost impacts (average and range) of converting raw biomass to pellets when facing variable year-to-year supplies
5 – Future Work

- Cost impacts of UT logistics demonstration project (LEAF)
  - Building on ORNL analysis of other logistics demonstration projects
  - Major goal will be to leverage field data from this project to inform INL and ORNL depot analysis

- Dynamics of multi-feedstock supply systems
  - Inventory management
  - Just-in-time delivery
  - Equipment utilization
Summary

GOAL: Build and apply simulations of biomass supply chains to address questions on feedstock cost, quantity, and quality

APPROACH: Integrating biomass resource assessment, feedstock logistics models, transportation and siting model, and advanced visualization

IMPACTS: (a) Expanded Billion-Ton projections to reactor throat, (b) improved moisture modeling, (c) evaluate industrial relevance of feedstock blends
Additional Slides
Responses to Previous Reviewers’ Comments

Overall Impressions

- Overall, the project is a useful integrating activity and should continue to focus on improving input data to represent realistic business scenarios.
- Overall, this is a good project. The team is responding to current needs and refining their analytical tools to reflect state-of-the-art.
- BETO has accomplished a lot with its modeling work and has led the way in many important aspects. This is a good time for BETO to commit itself to developing linked, verified, tested models that describe the economic and environmental performance of managed bioenergy systems all the way from the sub-field scale to the national scale. These models are needed also to bring along the rest of the society. We have to show how sustainably managed bioenergy systems can help achieve national economic and environmental goals.
- The structure and approach is quite solid, but this project is all about getting ground-truthed data. I see a major weakness around the data for the logistics portion that needs to be improved. As the presenter mentioned, models can be made around anything, but the relevance has everything to do with the data and assumptions informing the model.

PI Response to Reviewer Comments

- Thank you for the encouraging and constructive feedback from the reviewers. We appreciate that the reviewers recognized our efforts to construct high-quality, accurate simulation models for better understanding of the impact and challenges of biomass supply chains. We agree that a key factor to success of this project is to base analyses on commercial-scale data. To do this, we are continuing efforts to build and strengthen partnerships with feedstock suppliers and biorefineries for knowledge and data sharing.
Publications, Patents, Presentations, Awards, and Commercialization

Publications
5. Ebadian, M., S. Sokhansanj, and E. Webb. 2016. Estimating the required logistical resources to support the development of a sustainable corn stover bioeconomy in the USA. *Biofuels, Bioproducts, and Biorefining* 11:129-149

Presentations