DOE Bioenergy Technologies Office (BETO) 2015 Project Peer Review

1.2.3.1
Biomass Feedstock Supply Modeling

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Feedstock Supply and Logistics

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Goal Statement

Build and apply simulations of biomass supply chains
Towards reliably, affordably deliver a billion tons of on-spec biomass each year

Perform experiments to test equipment designs and supply chain configurations

Characterize impacts of variability and uncertainty

Identify risk-reduction strategies

Optimize feedstock supply logistics
Quad Chart Overview

Timeline

- 2007
- 2017
- 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></th>
<th>Total Costs FY 10–FY 12</th>
<th>FY 13 Costs</th>
<th>FY 14 Costs</th>
<th>Total Planned Funding (FY 15-Project End Date)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DOE Funded</strong></td>
<td>$1,716,474</td>
<td>$502,421</td>
<td>$543,109</td>
<td>$3,271,444</td>
</tr>
<tr>
<td><strong>Project Cost Share (Comp.*)</strong></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Partners

Collaborations

- Idaho National Laboratory
- FDCE
- Genera Energy, LLC
- Auburn University
- AGCO
- SUNY
- University of British Columbia
- University of Texas at San Antonio
1 - Project Overview

Working across entire terrestrial and algal feedstock supply chains

* Upcoming in FY15
## 2 – Approach (Technical)

### Major Challenges

<table>
<thead>
<tr>
<th>Challenge</th>
<th>Critical Success Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modeling systems that do not yet exist at commercial scale</td>
<td>• Adapting strategies and algorithms applied for other industries</td>
</tr>
<tr>
<td></td>
<td>• Incorporate best data from industry and academic partners</td>
</tr>
<tr>
<td>Delivering feedstocks that meet moisture specs while reducing costs</td>
<td>• Comprehensive, systems-based approach to evaluating moisture management that includes natural and mechanical drying technologies</td>
</tr>
<tr>
<td>Optimizing supply chain design for local feedstock availability</td>
<td>• Developed a spatial analysis approach that accounts for local feedstock availability and infrastructure</td>
</tr>
<tr>
<td>Developing financially stable and affordable algae biofuel production systems</td>
<td>• Constructing simulation models that integrate algal biofuels with production of high-value coproducts</td>
</tr>
<tr>
<td></td>
<td>• Applying lessons learned in assembling terrestrial feedstock supply chains</td>
</tr>
</tbody>
</table>
## 2 – Approach (Management)

<table>
<thead>
<tr>
<th>Major Challenges</th>
<th>Critical Success Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integrity of simulations</td>
<td>• Assemble a diverse research and advisory team to develop unbiased solutions for widespread benefit.</td>
</tr>
<tr>
<td>Impact of simulation results</td>
<td>• Consistent communication with industry partners to maintain awareness of challenges encountered in industry development</td>
</tr>
<tr>
<td>Simulation accuracy</td>
<td>• Adequately verifying and validating model performance</td>
</tr>
<tr>
<td>Acceptability of simulation results</td>
<td>• Clear communication and demonstration of simulations with stakeholders</td>
</tr>
</tbody>
</table>
Validation of high-tonnage logistics demonstration projects using IBSAL

**Cost improvements over baseline systems**
- AGCO = $13/dry ton
- FDCE = $13/dry ton
- TennEra = $4/dry ton
- SUNY = $17/dry ton
- Auburn = $17/dry ton
Sensitivity analysis of high-tonnage logistics systems

- ±25% change in equipment price only caused a $1/dry ton variation in feedstock cost
- ±25% change in diesel price – changed feedstock cost by $2-$5/dry ton (depends on transport distance)
- Throughput of harvest machinery significantly affects cost
  - **Field data critical for accurate harvest cost estimates!**
3 – Technical Accomplishments/ Progress/Results

INL PDU cost modeling

<table>
<thead>
<tr>
<th>Calculating grinding energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>**E = K_R \left( \frac{1}{L_p} - \frac{1}{L_f} \right) **</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Shredder</th>
<th>Hammermill</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial size (mm)</td>
<td>250</td>
<td>25</td>
</tr>
<tr>
<td>Final size (mm)</td>
<td>25</td>
<td>2</td>
</tr>
<tr>
<td>Moisture content (% wb)</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>10,000</td>
<td>10,000</td>
</tr>
<tr>
<td>Power input (kW)</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Energy in put (kJ/kg)</td>
<td>5.54</td>
<td>70.84</td>
</tr>
<tr>
<td>Throughput (kg/hr)</td>
<td>32467.5</td>
<td>2540.9</td>
</tr>
<tr>
<td>Processing time (min)</td>
<td>29</td>
<td>365</td>
</tr>
<tr>
<td>Grinder cost ($/ton)</td>
<td>$6.41</td>
<td>$20.78</td>
</tr>
</tbody>
</table>
Simulation of logging residue collection and transportation

- In conventional whole-tree harvest systems, moisture and ash contents are higher than desired.
- Developing Cost-of-Quality model to consider tradeoffs between investing in moisture and ash reduction strategies and using as a low-cost blending feedstock.
Systems approach to simulating industrial drying

- Drying can be the most expensive and energy-intensive operation in the feedstock supply chain.
- Energy required is determined by condition of incoming biomass (e.g., moisture content, particle size) and, in many cases, ambient conditions around dryer.
- Many drying models do not fully account for upstream operations (e.g., field drying or grinding) or ambient conditions.

Many biomass dryers are outdoors and heat required varies with ambient conditions.

Drying time increases with particle size.

Energy, and thus cost, for drying increases dramatically with incoming moisture content.
Spatial analysis of feedstock supply chains

- Successfully linked transportation and siting model with advanced visualization techniques to spatially explore feedstock supply options
- Supply Characterization Model (SCM) sites optimal facility locations (on a 50-mile grid) to minimize feedstock costs
- Utilizing interactive visualizations (developed in Tableau) of SCM outputs to determine where advanced feedstock supply options are needed to achieve cost and quantity targets.

Interactive analytical visualizations are a powerful research tool to explore large complex data sets
Spatial analysis of feedstock supply chains

- Developed method to compare feedstock costs as delivered to the reactor throat for various supply chain scenarios.
- Compared conventional (current technology) with an advanced system (high-moisture pelleting)

- Estimated a "discount" value for the advanced system to account for cost reductions from improved handling, more efficient conversion, etc.

If downstream advantages of advanced system value $16/dry ton or greater, it becomes a more attractive option.

If downstream advantages of advanced system value $11.25/dry ton or greater, it becomes a more attractive option.

- Applying this methodology to develop delivered supply curves for resource assessment projections.
Advanced Feedstock Supply System Workshop

Participants from the biorefinery, feedstock sourcing and supply, equipment, and data management industries along with academia were invited to provide input on:

**What are the barriers and solutions to supplying one billion tons of biomass by 2030?**
Advanced Feedstock Supply System Workshop Results

- Current large-scale biomass suppliers were concerned about availability of biomass at the farm
  - Need adequate incentives for producers
  - Mixed messages about sustainability inhibit producer involvement

- General consensus that the depot concept would overcome barriers in supplying one billion-tons annually, but concerned about how to get there from current systems

- Multiple markets for depots necessary to stand up feedstock industry

- Strategies for dealing with high-moisture biomass would be “game changer”

To supply a billion-tons annually, must reduce risk across the supply chain

Producers and land owners need stronger markets and clearer guidance on sustainability

Harvesters, brokers and biorefineries need advanced quality management strategies and higher efficiency/throughput equipment
Developed preliminary IBSAL-algae model

Utilizing unit operations models for algae processing developed by other labs and lessons learned in storage, transport, and handling of terrestrial feedstocks

Micro-Algae production

Recycles

Dewatering

Decision point on dry or wet pathway

Drying - granulating

Stable transportable dry microalgae

Similar to IBSAL Terrestrial

Production

Dewatering to paste Paste to powder

Stable pellets

Production

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Utilizing unit operations models for algae processing developed by other labs and lessons learned in storage, transport, and handling of terrestrial feedstocks

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Stable pellets
Feasibility assessment of dry algae feedstock

- Drying and pelletizing algae significantly increases efficiency of transportation and handling and reduces costs.
- Preliminary feasibility assessment:
  - Assumed value of delivered algae pellets = $162.40/dry ton
  - The cost of producing pelleted microalgae to harvest stage is back calculated to $26.17/ton
  - BETO’s MYPP (2014) projections estimates algae production cost at $32.82/dry ton. Reducing drying costs by $6.65/ton will make drying and pelletization economical
3 – Technical Accomplishments/ Progress/Results

Linking algae resource assessment, production, and logistics

- Algae produced in polyculture systems have larger variations in material properties that impact system performance along the entire supply chain

- **Collocating algae processing operations with waste heat sources has potential to significantly reduce drying costs**

![Diagram showing algae processing and logistics](image)

- The solid content of aqueous algae is increased almost 5 fold

- Waste heat from
  - Ethanol plants
  - Power plants
  - Cement plants
  - Food processing plants

- Algae produced in polyculture systems have larger variations in material properties that impact system performance along the entire supply chain.

- Collocating algae processing operations with waste heat sources has potential to significantly reduce drying costs.
4 – Relevance

• **Evaluate new technologies and systems**
  – IBSAL simulations of DOE-funded logistics demonstration projects showed that these systems provide cost improvements over baseline systems at commercial scale
    • Reductions of $13-17/dry ton make it possible to achieve $80/dry ton delivered cost target

• **Characterize impacts of uncertainty and variability**
  – Can perform “experiments” with supply chain configurations/technologies that would be cost prohibitive to test at commercial scale

• **Spatial analysis of supply chains based on resource availability**
  – New spatial analysis approach makes it possible to determine where systems work and to refine costs based on local and regional conditions.
  – Approach being used to develop reactor throat supply curves for BT16
5 – Future Work

- **Spatial analysis of biomass supply chains**
  - Consider impacts of reduced biomass availability due to drought or other system shocks
  - Leverage tools and methodology developed in this project to create reactor-throat supply curves for 2016 Billion-Ton Report Update

- **Supply chain business costs**
  - In response to criticism that simulated costs are lower than can be achieved in practice, we are preparing for a case study analysis to estimate costs of overhead, equipment transport, etc.

- **Moisture management**
  - Developing maps of moisture content at harvest and a spatial analysis to determine where field drying of residues is feasible
  - Linking models of moisture changes across the supply chain to build more comprehensive simulations that better account for moisture impacts

- **Build IBSAL-algae simulation equations and validate**
  - Analogous to terrestrial model to estimate costs, energy input, and carbon accounting from the growth of the algae to harvest and post harvest systems (including co-location fro CO2 and heat recovery)
Summary

- Leveraging relationships with industry, labs, and academia to create accurate, impactful simulations of terrestrial and algal feedstock supply chains
  - Quantifying cost improvements of harvest, collection, storage, and transportation industry and academia-led demonstration projects
  - Developing/refining algorithms for advanced biomass processing
  - Evaluating logging residue collection systems
  - Modeling “cost-of-quality”
  - Developing comprehensive, systems-based moisture management strategies
  - Resource-based spatial optimization of feedstock supply chains
  - Algal feedstock pond–to-reactor supply chain analysis

- Linking IBSAL simulation results with a transportation model and advanced visualization tool to develop interactive data visualizations for experimenting with biomass supply chain scenarios
  - Developing reactor-throat supply curves for 2016 update to Billion-Ton Report
## Responses to Previous Reviewers’ Comments

<table>
<thead>
<tr>
<th>2013 Reviewer Comment</th>
<th>Response</th>
</tr>
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<tbody>
<tr>
<td>...I can assume work with this model will continue. However, the future of IBSAL was not sufficiently discussed.</td>
<td>Development and refinement of IBSAL continues with the addition of new feed stocks (e.g., algae), incorporation of new capabilities (e.g., drying), and algorithms to better track quality along the supply chain (e.g., moisture). IBSAL will be an integral part of our new spatial analysis capability for biomass supply chains.</td>
</tr>
<tr>
<td>Broader communication with other non-funded companies and universities will be important to leverage this federal investment for public benefit. BETO should be more actively developing industry advisory groups and other feedback mechanisms to drive analysis toward critical industry needs.</td>
<td>Agreed. This was a major motivation behind the Advanced Feedstock Supply Systems workshop which included companies and universities that have received federal funds and some that have not.</td>
</tr>
</tbody>
</table>
Publications, Patents, Presentations, Awards, & Commercialization


## Preliminary sensitivity analysis of algae logistics operations

### Power input to algae centrifuge vs. change in operating conditions

<table>
<thead>
<tr>
<th>Change in Operating Conditions</th>
<th>kW/ton</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotational speed from 1500 to 3000 (rev/min)</td>
<td>0</td>
</tr>
<tr>
<td>Outer radius of the centrifuge from 0.12 m to 0.15 (m)</td>
<td>15</td>
</tr>
<tr>
<td>Flow rate of algae slurry from 0.25 to 0.5 (m^3/s)</td>
<td>30</td>
</tr>
<tr>
<td>Denser fraction (algae solids) from 1050 to 1313 (kg/m^3)</td>
<td>45</td>
</tr>
<tr>
<td>Lighter fraction (liquid) from 1000 to 750 (kg/m^3)</td>
<td></td>
</tr>
<tr>
<td>Inner radius of centrifuge from 0.10 m to 0.11 (m)</td>
<td></td>
</tr>
</tbody>
</table>

Additional Slides

- IBSAL Marches in time to establish pond’s operating parameters to minimize the logistical costs associated with handling solid concentrations and flow rates

![Graph showing daily micro-algae yield](image)

**Daily Micro-algae yield using kinetic equations for algae growth model and the TMY (Typical Meteorological Year) weather data for Knoxville TN.**

<table>
<thead>
<tr>
<th>Basic assumptions on pelletized micro-algae production dry mass, water and land requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microalgae production (mass) in a year (tonne)</td>
</tr>
<tr>
<td>Number of working days (days)</td>
</tr>
<tr>
<td>Daily production rate (kg d⁻¹)</td>
</tr>
<tr>
<td>Microalgae average concentration (g L⁻¹)</td>
</tr>
<tr>
<td>Number of ponds</td>
</tr>
<tr>
<td>Total pond area required (ha)</td>
</tr>
<tr>
<td>Outlet flow rate from each pond (m³ h⁻¹)</td>
</tr>
<tr>
<td>Outlet flowrate from all ponds (m³ h⁻¹)</td>
</tr>
</tbody>
</table>

The following table offers an IBSAL method of cost analysis that would contribute to a better understanding of microalgae harvest economics and identify opportunities to reduce costs. We assume that the final microalgae product is available in pellet form at a density of about 750 kg and a moisture content of 6%. The value of dry microalgae in this form depends on four products: biofuel, animal feed, fertilizer, and pharmaceutical/food additives. The following Table 1 allocates the potential mass fraction of microalgae for each of the applications based on the composition of the microalgae; i.e., 50% lipids, 40% proteins; 8% minerals; 2% vitamins and coloring agents. The potential market price for each fraction is given in dollars per ton. The combination of mass fractions and the expected value brings the value of the dry microalgae pellets to $162.40 per ton. The data from this table is used to do reverse cost calculations in

Percent of the dried microalgae used for four applications and the assumed unit cost for each fraction. In this table cost is equivalent to the price that each fraction can fetch

<table>
<thead>
<tr>
<th>Uses of algae biomass</th>
<th>Cost ($/ton)</th>
<th>Fraction (%)</th>
<th>Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass feedstock for biofuel</td>
<td>$80</td>
<td>50</td>
<td>$40.00</td>
</tr>
<tr>
<td>Animal feed</td>
<td>$250</td>
<td>40</td>
<td>$100.00</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>$30</td>
<td>8</td>
<td>$2.40</td>
</tr>
<tr>
<td>Pharmaceutical/food additives</td>
<td>$1,000</td>
<td>2</td>
<td>$20.00</td>
</tr>
<tr>
<td>Sum</td>
<td></td>
<td>100</td>
<td>$162.40</td>
</tr>
</tbody>
</table>