DOE Bioenergy Technologies Office (BETO) 
2019 Project Peer Review

WBS 1.2.3.3 Biomass Feedstock User Facility – 
Improving Bale Deconstruction and Material Flow

March 4
Bioenergy Technologies Office (BETO)
Advanced Development and Optimization (ADO)
Principal Investigator – Neal Yancey
Idaho National Laboratory

This presentation does not contain any proprietary, confidential, or otherwise restricted information
Goal Statement

• This project has both technical and programmatic goals
  – Technical goal – decouple bale deconstruction from size reduction and develop sensor and visualization modeling capabilities to enable an “Energy to Molecules” concept
    • Create a uniform flow from heterogeneous non-uniform feedstocks
    • Create uniform quality feedstocks from highly variable source materials
    • Determine and model material flow and deconstruction phenomena inside milling/grinding equipment using real time sensors and 3D imaging
  – Programmatic goal – increase BFNUF utilization to greater than 60%
• The project advances the BETO goal of growing a bio-economy by developing robust biomass preprocessing strategies to overcome feedstock variability and feed handling challenges faced by the biofuel and bio product industries
• The successful achievement of these goals will result in successful bio refinery startup and operation – leading to improved National energy independence.
<table>
<thead>
<tr>
<th>Key Milestones</th>
<th>FY 2019</th>
<th>FY 2020</th>
<th>FY 2021</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Test 4 debaling approaches</td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
</tr>
<tr>
<td>2) Report results from 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3) Procure and Install selected debaler</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4) Demonstrate 50% increase in throughput and 50% decrease in particle size variation</td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
</tr>
<tr>
<td>5) Identify 3D imaging sensors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6) Procure and Test 3D sensors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7) Go/no-Go 80% increase in throughput, 30% decrease in energy and variability</td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
</tr>
<tr>
<td>8) Demonstrate 3D imagery inside milling equipment – 25% increase in amps and 25% increase in throughput @ stage 2</td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
</tr>
<tr>
<td>9) Implement decoupled bale deconstruction for PDU</td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
</tr>
<tr>
<td>10) Utilize PDU control system to achieve autonomous adaptive control</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11) Complete a 20 ton demonstration</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12) Using graded deconstruction approach – achieve 75% average FLA and 50% improved system throughput</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Start Date: Today
# Project Budget Table - Example

<table>
<thead>
<tr>
<th>Budget Periods</th>
<th>Original Project Cost (Estimated)</th>
<th>Project Spending and Balance</th>
<th>Final Project Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>BP1 (BFNUF User Facility)</td>
<td>$4.35M</td>
<td>$387K</td>
<td>$3.96M</td>
</tr>
<tr>
<td>- In-Situ Process Monitoring</td>
<td>$596K</td>
<td>$70K</td>
<td>$526K</td>
</tr>
<tr>
<td>- User Facility Maintenance</td>
<td>$820K</td>
<td>$80K</td>
<td>$740K</td>
</tr>
<tr>
<td>- Testing Bale Deconstruction/Fractiional milling</td>
<td>$600k</td>
<td>$191K</td>
<td>$415</td>
</tr>
<tr>
<td>- Automated Test Report and Database Management</td>
<td>$200K</td>
<td>$46K</td>
<td>$154K</td>
</tr>
<tr>
<td>- CRADA Light DFO Collaborations</td>
<td>$1M</td>
<td>0</td>
<td>$1M</td>
</tr>
<tr>
<td>- Equipment Upgrades</td>
<td>$1M</td>
<td>0</td>
<td>$1M</td>
</tr>
</tbody>
</table>
Quad Chart Overview

**Timeline**
- Project start date: 10/01/18
- Project end date: 09/30/21
- Percent complete: 12%

**Barriers**
- ADO-H Materials Compatibility, and Equipment Design and Optimization -- Inability of equipment to eliminate surges in biomass
- At-B Analytical Tools and Capabilities for System-Level Analysis – Variability in biomass properties and ability to identify appropriate sensors to accomplish.

**Budget**

<table>
<thead>
<tr>
<th></th>
<th>Total Costs Pre FY 17</th>
<th>FY 17 Costs</th>
<th>FY 18 Costs</th>
<th>Total Planned Funding (FY 19-FY21)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOE Funded</td>
<td>$1.95M</td>
<td>$1.74M</td>
<td>$4.35M</td>
<td></td>
</tr>
</tbody>
</table>

**Partners**
- NREL, PNNL, LBL
- Virginia Commonwealth University
- Forest Concepts
- Bliss
- Vermeer
- Rotex
- Warren and Baerg
- Bulk Handling Systems
- B. Hames Consulting
1 - Project Overview

Project Objectives for Improving Bale Deconstruction and Improving Material Flow:

*Solve industrial feed handling problems associated with variability in biomass properties by developing a segmented bale deconstruction process that prevents slugging or surging of biomass – improving throughput and product quality.*

<table>
<thead>
<tr>
<th>Technology</th>
<th>Throughput (T)</th>
<th>Quality (Q)</th>
<th>Reliability (R)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional Feedstocks Preprocessing</td>
<td>Low T, uneven flow, inability to adjust to changing biomass characteristics</td>
<td>Low Q, inability to maintain consistent particle size, ash content, and other compositional components</td>
<td>Low R, frequent plugging often resulting in equipment damage</td>
</tr>
<tr>
<td>Advanced Feedstock Preprocessing</td>
<td>High T, able to adjust to changing properties to achieve uniform flow</td>
<td>High Q, able to adjust autonomously to maintain quality compositional characteristics</td>
<td>High R, less down time observed</td>
</tr>
</tbody>
</table>

*Conventional feedstock processing results in:*

- Down time to unplug equipment
- Down time replacing damaged equipment
2 – Approach (Technical)

• Technical Approach (Quality by Design)
  – Decouple bale deconstruction from 1st stage size reduction
  – Test to determine improved material flow following bale deconstruction
  – Develop segmented bale deconstruction methodology for the PDU
  – Remove rock/tramp metal from infeed early in the process
  – Develop screening methodology to achieve consistent particle size regardless of infeed conditions
  – Develop inline and visual 3-D sensors to monitor real time quality metrics and equipment performance criteria
  – Increase User Facility Participation

• Success Factors
  – Achieve uniform flow, name plate throughput, decrease particle size variability
  – Engage industry to identify major equipment issues
  – Identify real time, inline sensors that measure critical material characteristics or mechanical operating conditions that have otherwise not been observed.
  – Identify industrial partners who will team with the BFNUF to demonstrate commercial viability of this project

• Potential Challenges
  – Lack of reliable in-line sensors
  – Unable to meet feedstock specifications for various conversion pathways
  – Unable to bring in enough business to be self-sustaining.
Process Operations Block Diagram – BFNUF PDU

1. **De-Baling Operation**
   - **CONVEYOR STEP 1**
     - **FIRST STAGE SIZE REDUCTION**
       - **CONVEYOR STEP 2**

2. **COURSE SCREENING**
   - **OVERS**
     - **CONVEYOR STEP 3**
       - **SECOND STAGE SIZE REDUCTION**

3. **FINAL SCREENING**
   - **ACCEPTS**
     - **OVERS RECYCLED**
       - **Removal of fines and ash**

4. **ON SPEC MATERIAL**
      - **Biomass Conversion Pathway**
Typical corn stover
Color could be used to detect level of degradation!
Heat degraded stover

3D and Inline Sensor Block Diagram – BFNUF PDU

Raw Biomass Feedstocks

De-Baling Operation

FIRST STAGE SIZE REDUCTION

COURSE SCREENING

SECOND STAGE SIZE REDUCTION

FINAL SCREENING

Moisture, Ash, Particle Size

Typical corn stover

Heat degraded stover

3D Imagery
- Thermal
- Visual
- Mass Flow

High Speed Image of Hammer Impacting Stover
2 – Approach (Management)

• **Project Scope for User Facility**
  – Decouple bale processing from size reduction and initial segmented bale deconstruction
  – Single unit operation and integrated testing (Using a Quality by Design approach)
  – Inline sensor development, particle image velocimetry and optical flow visualization
  – Proprietary projects pay 100%
  – Non-proprietary project’s required cost share

• **Management Tools**
  – BETO-sponsored and competitively awarded projects have priority
  – DOE review and approval of external projects
  – Industry Advisory Board
  – Marketing/trade shows for networking

• **Success Factors**
  – Become Self Sustaining – Increase number of projects, users, publications/patents
  – Knowledge gained and improve technologies for customers
  – Significant improvements to reliability of preprocessing systems
  – Achieve nameplate throughput and uniform quality
  – Successful identification and implementation of inline sensors

• **Challenges:**
  – Meeting feedstock specifications for different conversion pathways
  – Getting enough business to be self sustaining
3 – Technical Accomplishments/Progress/Results (cont’d)

- **Testing bale feeding technologies**
  - Low speed / high torque -- similar to that used in the livestock industry
  - Medium speed high torque bale processor – Industry Scale (Warren and Baerg and Conners)
  - Round and square bale capabilities

- **We are currently comparing the data from those tests**

- **Work with the User Facility is usually slowest during the 1st Quarter. However, there were 15 tests conducted on the user facility during FY19 Q1:**
  - 8 tests with round and square bales with debaling equipment
  - 1 grinding test with miscanthus
  - 1 grinding test with MSW
  - 2 drying tests with pine
  - 2 drying tests with brewery waste
  - 1 grinding test with pine
Comparison of Stage 1 and stage 2 amperage and product level in the conveyors during FY18 FCIC low temperature baseline testing

This demonstrates how inconstant the flow of biomass is – resulting in very poor performance

- Average current in stage 1 Grinder is 69 amps
- Normal full load operating current is 150 amps.
- Peaks exceed 3X full load amps while the average is less than ½ of the FLA

- Average current in stage 2 Grinder is 72 amps
- Normal full load operating current is 170 amps
- Peaks are 2X FLA and the average is less than half FLA

- Average product flow is 2 inches which is ~ same as the through put (2 ton/hr)
- Peaks are greater than 12 inches
- The name plate through put is 5 tons per hour so again, less than half of design capacity
• Test bale processors in FY19 Q1
• All of the bale processors showed improvements in material flow
• The design pictured at right has a patented dual feed rate for blending bales of different moisture or other attributes at different feed rates
Low rpm debaling results in less fines generated and a uniform flow into downstream processing.

Mechanical product level sensors measured the flow of material from the debaler.
Uneven Flow caused by high speed combined bale processing and size reduction

Much less variation in flow when bale processing is decoupled from size reduction
4 – Relevance

Biomass feed handling remains one of the major barriers for success in the cellulosic biomass industry

- Biomass handling problems were blamed for slow start-up of biorefiners. This was confirmed in the 2018 FCIC baseline tests where material handling problems, were the primary reason for failure and inability to achieve nameplate throughput

- **Overcoming material surging will:**
  - Increase system throughput
  - Improve particle size uniformity
  - Reduce energy costs
  - Increase system reliability
4 – Relevance

• Rand Corporation study (Merrow, 1984) showed that plants that process bulk solids typically operate at less than 50% of design capacity the first year of operation – Performance of 37 new plants using data provided by 25 companies.

• Problems generally relate to an inadequate understanding of the behavior of elastic & compressible particle systems (Bell, 2005). This observation is still true today.
4 – Relevance

• User Facility projects depend upon collaboration with industry to address real world feedstock handling problems
• User Facility projects are helping INL and BETO
  – Understand range of feedstock specifications for different conversion pathways
  – Understand the gap between specifications and what is achievable at an industrial scale
  – Identify innovative solutions to industrial preprocessing needs (closing the gap)
  – Supply data to support BETO techno-economic assessments and state of technology reports
• Collaborations are helping our partners (users)
  – Develop robust feedstock preprocessing technologies that enhance the reliability of integrated biorefineries
  – Scale up from pilot scale to industrial scale
5 – Future Work

• Complete testing, reporting and implementation of bale processing prior to stage 1 grinding

• Develop Segmented Bale Deconstruction using a Quality by Design approach—integrate bale processor, stage 1 and 2 milling, screening to achieve 50% improvement in throughput and reduce particle size variation

• Identify and implement 3D imagery within the milling process

• Go/No-Go Milestone (Q2 FY20) will demonstrate the ability to eliminate material slugging and incorporate fractional milling/screening to increase throughput by 80% over baseline methods and achieve 30% reduction on particle size variability.

• This project has just completed the 1st quarter of work and is still on budget to complete all of the tasks as outlined.

• Expand user facility capabilities
  – Add screening system to facilitate fractional milling and improve particle size distribution of feedstock
  – Add inline/real-time sensors
Summary

1. Overview
The INL BFNUF User Facility provides a critical capability for projects that require an integrated system with data logging/analysis capability that are too complex for industry test laboratories/facilities. Enabling the ability to scale up pilot scale solutions to achieve industrial scale validity.

2. Approach:
Eliminate material slugging by decoupling bale deconstruction with 1st stage size reduction. Engage industry with project development to ensure relevance to industry and DOE/BETO

3. Technical Accomplishments/Progress/Results
Eliminate material slugging/improve material flow
Enable real-time sensor utilization

4. Relevance
Developing robust feedstock preprocessing technologies will help accelerate the expansion of a bioeconomy
Increase product quality for down stream conversion processes

5. Future work
Develop 3D imaging within the grinder chamber to increase understanding and cause/effect of material properties and product quality.
Additional Slides
Publications, Patents, Presentations, Awards, and Commercialization

Publications:


Tumuluru et al., Impact of Feedstock Supply System Unit Operation on Feedstock Cost and Quality for Bioenergy Applications. Chapter 1. 2016


Publications, Patents, Presentations, Awards, and Commercialization

Patents/Invention Disclosures

- Intelligent, adaptive control system for integrated preprocessing of biomass feedstocks
- Bale Grinder Flow Controller
- Method for producing cellulosic ethanol in dry grind ethanol plants
- Biomass Axial Flow Preprocessing And Separation System
- Simultaneous Lignocellulosic Biomass Preprocessing And Drying
- Biomass Sizing And Thermal Densifying Unit
- Drying Of Biomass Bales Using Radiofrequency And Conventional Method
- Reducing Off-gas Emissions From Stored Woodchips, Sawdust And Wood Pellets