



DOE Bioenergy Technologies Office (BETO) 2021 Project Peer Review

WBS 3.4.1.202 Biomass Feedstock National User Facility – Improving Bale Deconstruction and Material Flow

Date: 3-24-21

Technical Area Session:

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INL

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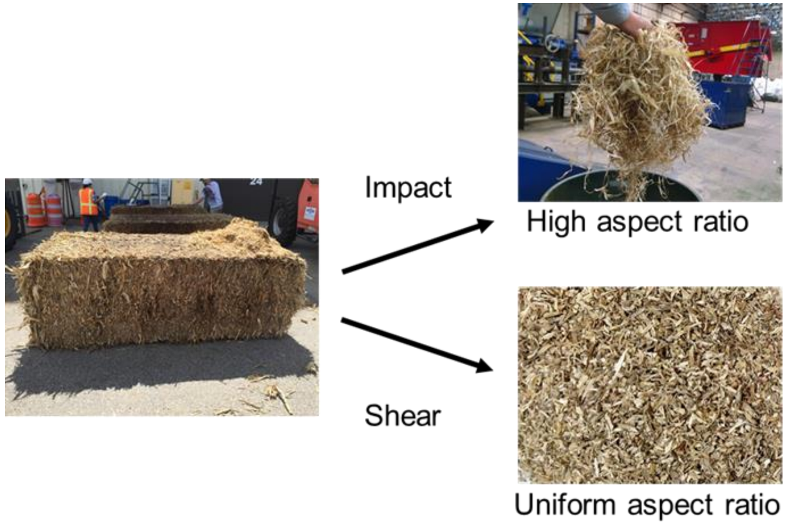
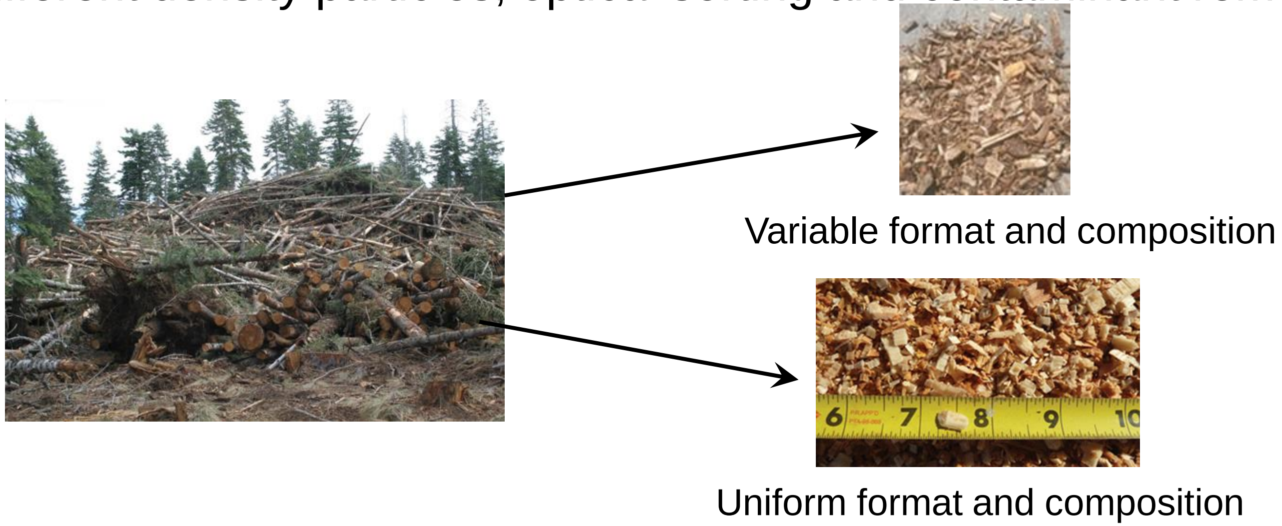
Project Overview

- **Objective:** Reduce the variability in raw feedstocks using a Quality by Design (QBD) approach beginning at the introduction of the biomass and continuing through the size reduction process. This will result in:
  - Reduction of fines generation and removal of contaminants (tramp metal, rock, soil, etc)
  - Controlling physical and chemical critical material attributes throughout the process
  - Managing flowability and achieving nameplate capacity and efficiency

  This will be accomplished by:
  - Eliminating high speed bale deconstruction for more uniform flow and particle size control
  - Replacing, when necessary, high speed impact size reduction mills with lower speed shear milling for 3-dimensional particle size control and fines reduction
  - Screening to achieve desired particle size and shape, and reduce over processing
  - Sorting to separate anatomical fraction, different density particles, optical sorting and contaminant removal.





Project Overview (con't)

- **Current Limitations:** Inherent physical and chemical variability in feedstocks inhibit their raw use in bioenergy processes leading to high inefficiencies, excessive process downtime, and uncontrolled costs with documented failures in the industry as a whole. Common high-speed milling operations do not address core problems of excessive fines, contaminants, and particle size and shape differences

- **Relevance:** Manage variability in preprocessing operations through:
  - Experimentally-derived interactions in material feeding
  - Machine learning and automation to minimize human error
  - Status of Technology (SOT)
  - TEA/LCA Implications:
    - Value proposition of ash removal on downstream equipment wear
    - Value proposition of material attributes on deconstruction reactor design/operation
- **Risks:**
  - Multi-dimensional, multi-scale problem
  - Scale up from bench, pilot, PDU
  - Timely adaptation of preprocessing equipment for maximum impact
  - Effective dissemination of tools and knowledge for maximum market impact

1 – Management

This project is managed by Neal Yancey. It is divided into 3 main task and 8 subtasks presented in the table below:

Subtask	Lead(s)	Major Responsibilities
Task 1 - Advanced Preprocessing Research and Development and Scale Up		
Task 1A	Neal Yancey	Material Introduction
Task 1B	Jordan Klinger	FY2022 Verification
Task 1C	Luke Williams	Hydrodynamic Separation
Task 2 - Machine Learning, System Automation, Sensor Development and Data Management		
Task 2A	Patrick Bonebright	Machine Learning and Automation.
Task 2B	William Smith	Sensor Development
Task 2C	Robert Kinoshita	Data Management
Task 3 - BFNUF Requests and Feedstock Supply		
Task 3A	Luke Williams	User Facility Requests
Task 3B	Neal Yancey	Feedstock Supply

Risks: Lack of communication between industry and laboratories; Lack of synergy between experimentation and modelers; lack of synergy between researchers at various laboratories

1 – Management (continued)

Communication strategy –Cross-task collaborations:

- PIs, Task Leads, LRM and BETO TMs monthly meetings
- Monthly subtask meetings
- Quarterly cross task collaborations
- Joint milestones with other Tasks
- Coordination with Task members on other tasks

Inter-Lab/Industry Collaborations:

- Partnering with NREL and Exxon Mobile
- Developing CRADA with Warren and Baerg
- User Facility Projects – GTI and RTI
- Participation with lab-industry partnerships (DFO projects)

Risks: Lack of communication between industry and laboratories; Lack of synergy between experimentation and modelers; lack of synergy between researchers at different laboratories

2 – Approach

Technical Approach:

- Develop new hypothesis - **overcoming inherent feedstock variability** based on previous experimental testing
- Develop methods based on experimental data to **achieve and predict 3 dimensional milling** approaches, feedstock sorting, and advanced fractionation.
- Determine process parameters to achieve quality attributes defined by the **2022 verification effort**
- Generate process data (i.e. throughput, energy requirements, etc.) to **inform TEAs/LCAs** and the 2022 verification

Challenges:

- Maintain connection with other national labs regarding process parameters for the most critical attributes
- Transition novel concepts into industrially relevant technology
- Coordinate experimental testing and results between tasks

Metrics:

- Demonstrate scale up of industrial relevant approaches that support TEAs/LCAs and the 2022 Verification
- FY21 Go/No Go –Complete the integration of fractional milling for pine and pine residue
  - Reduce standard deviation for amperage by 25% and increase throughput for woody biomass by 30%. Reduce the non white wood fraction (bark, needles, etc.) by 75% in the clean fraction.
- Demonstrate a systematic approach including product infeed, milling, sorting, and fractionation to multiple finished product lines. This will support SOT development and FCIC Task 8
- Demonstrate a 25% reduction in attrition (fines) combined with a 30% decrease in Ash in corn stover and pine

3 – Impact

Impact:

- Custom designed Low speed bale processors will support downstream separation and size reduction technologies designed to meet key material attributes
- Size reduction to achieve 3-dimensional control of particle size will improve flowability and conversion efficiency
- Separation to meet feedstock quality attributes resulting in increased operational and conversion efficiency and reliability
- Subsequent conversion unit operations will benefit from predictable material attributes and controllable process parameters that result in improved conversion performance and reliability

Municipal Waste

Agricultural Residue

Corn Stover

Hammer Milled

Sheer Milled

Air Classification of Forest Residue

Dissemination:

Near term:

- Peer-reviewed journals and trade journals
- Virtual and Real Industry Workshops
- Collaboration with industry partners
- Conference presentations

Long term:

- Demonstrate applicability to industrial stakeholders
- Design control capabilities to mitigate feedstock variability
- Team with industry to bring technology to market

4 – Progress and Outcomes

Improved Material Introduction

Low Speed Specifically Designed Material Introduction:

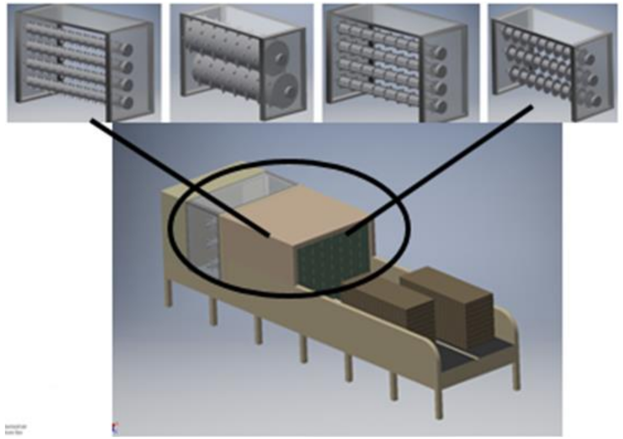
- **Lower attrition rates**
- **Support down stream anatomical fractionation**
- **Consistent particle sized and distribution**
- **Lower energy requirements**
- **Consistent feeding and conveyance**

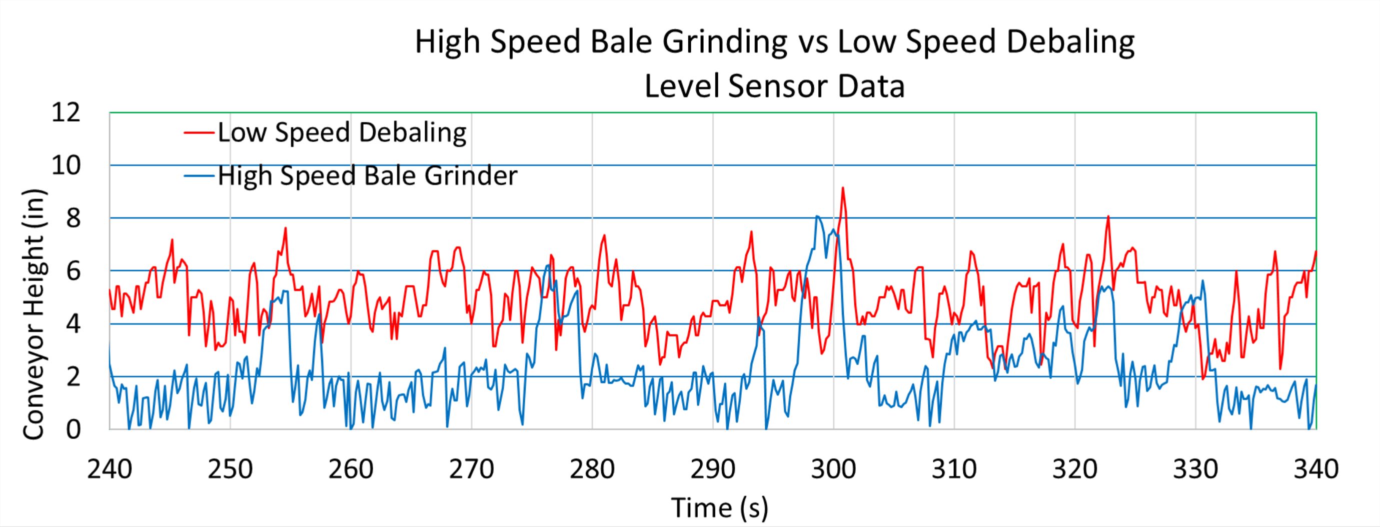
Description

High speed bale deconstruction results in excessive generation of fines, uneven flow and increase energy costs.

Value of new tool

Fewer material losses as fines, better performance in downstream conversion, improves contaminant removal and enables anatomical or waste type fractionation.





	Mean (mm)	% less than 1 mm	% less than 6 mm
Vermeer 6 inch	6.01	5%	47%
Vermeer 3 inch	5.97	12%	62%
Bale Processor	15.9	2%	15%

Air Classification

Air Classification is used at the BFNUF to:
- **Achieve anatomical fractionation**
- **Improve contaminate removal**
- **Separate materials of different densities**
- **Low-cost method to achieve separation**

Description

At the BFNUF air classification is used to separate anatomical fractions as well as to separate tissue fractions or MSW types in milled materials.

Value of new tool

Separation of the anatomical fractions allows the BFNUF to look at milling approaches tailored to those fractions to achieve specific CMAs for that material.

Clean Chips

Raw Material

Bark/Needles

Large Scale Air Separation:
- Separates stalks, cobs, leave and husks
- Separates bark, needles, and whitewood

Small Scale Air Separation:
- Tissue separation
- Separates bark, needles, and whitewood
- MSW fractionation

	Clean Chips	Bark	Bark and Wood Connected	Needles	Unclassified Particles
Raw Forest Residue	73%	7.0%	3.5%	0.8%	15.2%
After Separation High Moisture	85%	4.0%	0.58%	0.12%	10.28%
After Separation Low Moisture	94.2%	2.1%	0.6%	0.10%	3.0%

Advanced Milling

Advanced Milling Achieves 3-Dimensional Particle Generation Using:

- **Shear milling, knife milling, and impact milling**
- **Recycling overs to achieve target particle size**
- **Screening to remove fines**
- **Specific milling targeted to the material/tissue type**

Description

The BFNUF utilizes a number of milling approaches that are aimed at achieving specific particle size and dimensions. This can be achieved for each anatomical fraction or tissue type following successful anatomical or tissue separation.

Value of new tool

Controlling particle size at 3 dimensions of the particle for each feedstock.

- Improved flowability
- Increased conversion performance

Hammermill

Knife mill

Crumbler

Hammermilled Corn Stover

Shear milled Corn Stover

Hammer Milled MSW

Shear Milled MSW

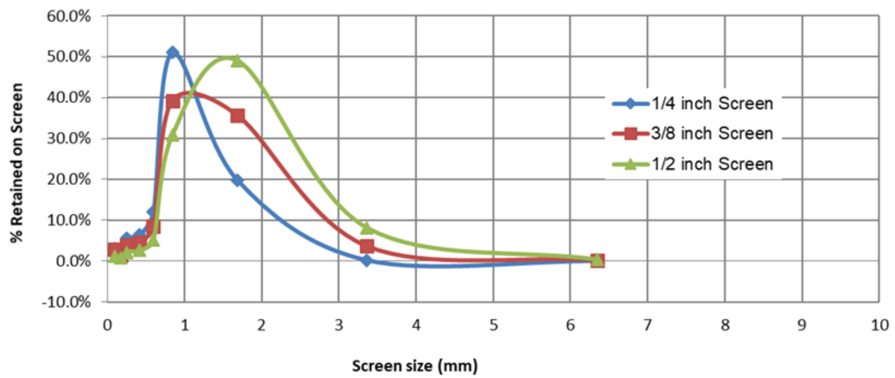
Screening Implementation

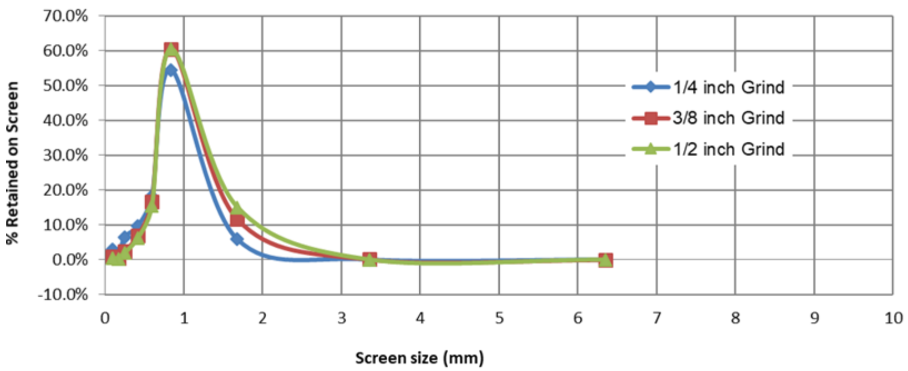
Appropriate screening timed specifically in the process will result in:

- **Lower attrition rates**
- **Support down stream anatomical fractionation**
- **Consistent particle sized and distribution**
- **Lower energy requirements**
- **Consistent feeding and conveyance**

Description

Screening Advances the Fractional Milling approach by reducing energy, improving particle sizes distributions, and removing contaminants.





Disc Screening:

- Contaminant removal
- Minimize attrition
- Supports anatomical fractionation

Orbital Screening:

- 3-dimensional particle
- Supports fractional milling
- Achieve CMAs

Hammermill Screen Size Used	Mean Particle size before screening	Mean Particle Size after screening	Grinding Energy kWhr/dry ton
¼ in. Grind	1.49 mm	1.30 mm	64.0
3/8 in. Grind	1.81 mm	1.48 mm	57.3
½ in. Grind	2.35 mm	1.56 mm	48.3

Density Separation

Separation based on density using a Specific Gravity table:

- **Separate fractions based on tissue type**
- **Separate MSW based on material or plastic type**
- **Requires uniform particle size.**

Description

The BFNUF uses the Oliver Specific Gravity table to separate tissue fractions in both woody and herbaceous material once it has been milled. MSW can also be fractionated into different densities of plastics, paper, fabric or contaminant removal

MSW

Low 45 kg/m3 Density

Medium – 67 kg/m3 Density

High - 223 kg/m3 Density

Specific Gravity Separation :

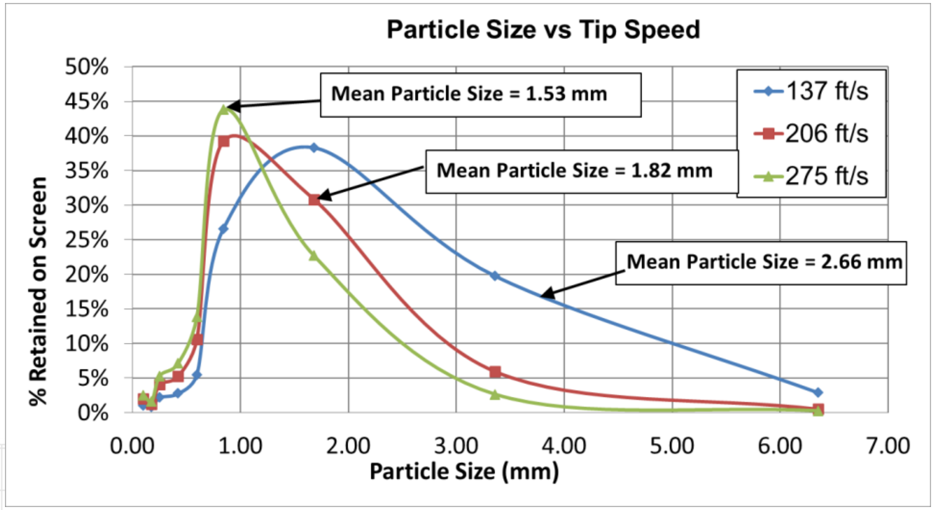
- MSW fractionation – separating fluff from discrete plastic particles above
- Tissue separation pith from rind of corn cobs on the left

Crumbled Corn

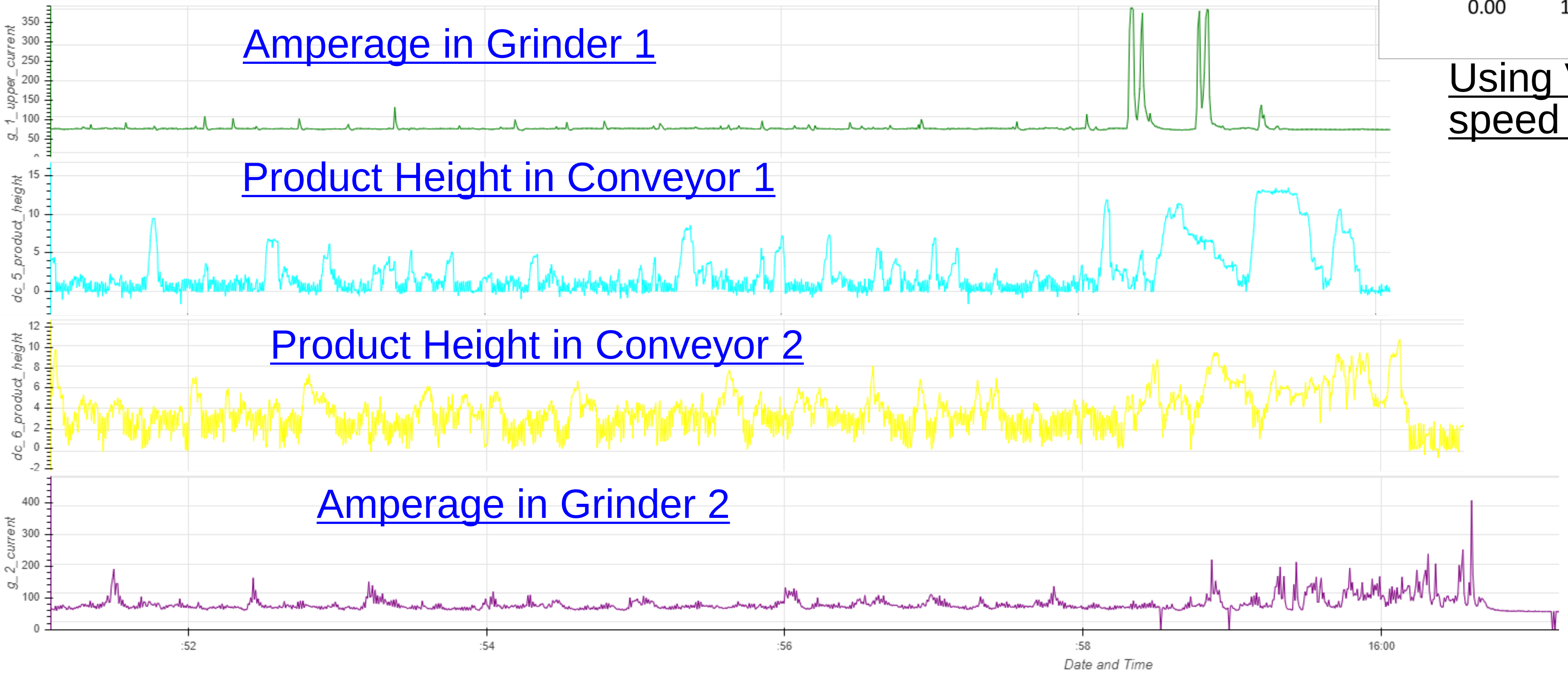
Sensor Development and Automation

Real Time monitoring and control results in:

- **Increased efficiency**
- **More uniform particle size and distribution**
- **Less down time**



Using VFDs to control Hammer tip speed reduces the generation of fines



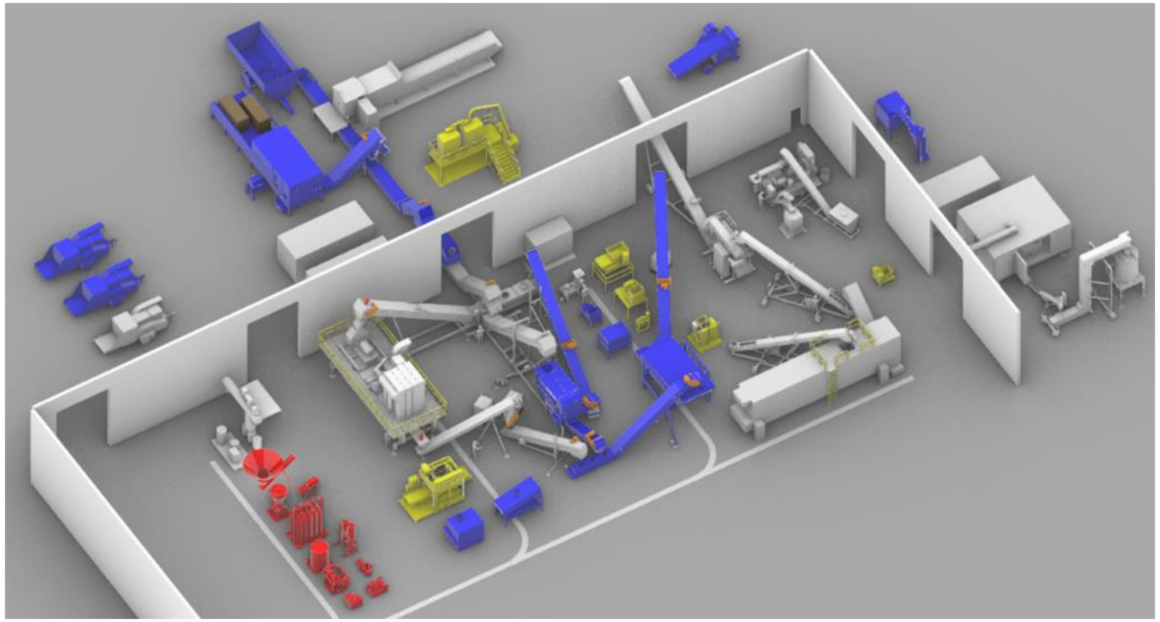
Description

Use Product Levels in Conveyors and physical material properties to predict and manage mill performance and material conveyance.
Use variable frequency drives to control hammer speed to manage particle sizes and fines generation

BFNUF an Industry Scale-up Test Bed

The BFNUF is a system of multiple preprocessing capabilities that can be used on a variety of feedstocks and industries to:

- **Improve material flow**
- **Increase feedstock value**
- **Remove inherent variability in highly variable feedstocks**



Description

The BFNUF incorporates a variety of preprocessing applications including:

- Material introduction – chippers, shredders, bale processors,
- Screening – disc, oscillating, shaking, PDU scale to bench scale screens
- Sorters – robotic, mechanical, air, density

With a central aim of

- Reducing energy costs
- Meeting physical and chemical material attribute
- Defining define process parameters for each unit operation

Value of new tool

Developing the biofuel industry by creating consistent feedstocks for a variety of conversion pathways.

Potential Customers & Outreach Plan

Biorefineries, mill operators and mill designers - GTI and RTI

Publication, trade shows and public release of code

Summary

Raw Biomass is not a feedstock it requires advanced milling approaches to create a uniform feedstock

Fractional Milling achieved:

- 55% reduction in amperage variability through 1) consistent feeding FY21 Q1 milestones required that the BFNUF meet the following goals using fractional milling of forest residue
- reduced the energy consumption by 25%
- More uniform particle size

Air Classification achieved

- 75% reduction in non-whitewood fraction of residue using air classification and screening
- Total ash reduction from 2.62% to 1.02%

Sorting and Density Separation

- Increase chemical and physical consistency
- Reduce contamination and variability

Summary

Potential Industries this research supports:

- Biorefineries
- Mill operators
- Mill designers

Value of the research and tools developed:

- Increased efficiency and performance -- less down time
- Reduced contamination and attrition
- Increase physical and chemical consistency in feedstock

WBS # 3.4.1.202

Timeline

- 10/01/2018 - 09/30/2021

	FY20	Active Project
DOE Funding	$1,713K	FY19- FY20- $2,306 FY21- $1,713 Total- $4,019

Project Partners (N/A)

Barriers addressed

Ct-A - Reducing variability through screening/sorting

Ct-C Improving preprocessing efficiency

Ct-J - Developing process integration to achieve material attributes

Ft-I - Integration and scale up

Project Goal

Develop science-based design and operational principles that improve feeding, handling, and control critical material attributes that have historically resulted in failure by the industry. Utilize a quality-by-design approach to create, quantify, and capture feedstock fractions with narrow physical and chemical quality distributions to support low and high temperature conversion processes.

End of Project Milestone

Completion of the Advanced Fractionation System Approach (including bale deconstruction, screening, air classification, and mechanical separation/sorting) and demonstration of Fractional Milling approach, resulting in a 25% reduction in fines generation, 50% increased system throughput, maintain an average milling amperage at 75% of full load amps, and 50% reduction in the standard deviation around the mean particle size.

Funding Mechanism (N/A)

*Only fill out if applicable.

Publications, Patents, Presentations, Awards, and Commercialization

Publications / Presentations:

- Klinger, J., D. Carpenter, V. Thompson, N. Yancey, R. Emerson, K. Gaston, K. Smith, M. Thorson, H. Wang, D. Santosa and I. Kutnyakov. 2020. Pilot plant reliability metrics for grinding and fast pyrolysis of woody residues. Accepted to *ACS Sustainable Chemistry & Engineering*, January 16, 2020.
- Sievers, D., E. Kuhn, V. Thompson, N. Yancey, A. Hoover, M. Resch, and E. Wolfrum. 2020. Throughput, reliability and yields of a pilot-scale conversion process for production of fermentable sugars from lignocellulosic biomass: A study on feedstock ash and moisture. Accepted to *ACS Sustainable Chemistry & Engineering*, January 16, 2020.
- Oral presentation: Neal Yancey. Improving Forest Residue Quality Through Air Classification and Specific Gravity Separation. IBBC 2020.
- Oral Presentation: Tiasha Bhattarcharjee, Jordan Klinger, Neal Yancey and Vicki Thompson. “Population Balance of Hammer Milled Loblolly Pine in ‘Once-through’ and ‘Fractional Milling’ Configurations” AIChE 2020 Annual meeting.
- Submitted Abstract to International Biomass Conference 2021. Neal Yancey. Reducing Ash and Improving Particle Size Distribution for Forest Residue Through Advanced Mechanical Preprocessing Techniques.

Additional Slides

Material Introduction

- **Low speed bale deconstruction reduces the generation of fines**
- **The new bale processor can be configured for a variety of feedstocks – corn stover, MSW, etc.**
- **This enables contaminant remover prior to size reduction**
- **After debaling, feedstocks can be easily sorted using screens, air classifiers, or robotic separators as needed**

	Mean (mm)	% less than 1 mm	% less than 6 mm
Vermeer 6 inch	6.01	5%	47%
Vermeer 3 inch	5.97	7%	52%
Bale Processor	15.9	2%	15%

Description

The Warren and Bearge bale processeor uses low speed debaling drums with fingers rather than knives or hammers to decompress and untangle the corn stover and create a uniform flow of biomass

Value of new tool

This tool allows for easy separation of rocks or tramp metal following the bale processor decreasing downstream equipment wear and reduces the generation of fines caused by high speed bale grinders

Potential Customers & Outreach Plan

Biorefineries, mill operators and mill designers

Publication, trade shows