April 5, 2023

**Neal Yancey**
BFNUF Operations Manager

# WBS 3.4.1.202 BFNUF PDU

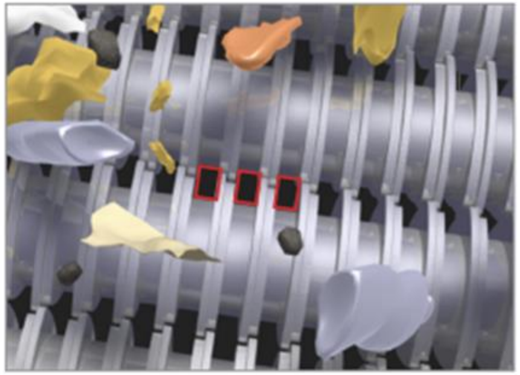
## DOE Bioenergy Technologies Office (BETO) 2023 Project Peer Review

# Project Overview

**Objective:** **Advance the TRL of new feedstock** processing technologies - moving technological developments from the bench to the pre-pilot scale. **Fractionating low-cost waste materials** into feedstocks that meet the critical attributes needed for conversion at downstream facilities. **Reducing variability** in raw feedstocks using a Quality by Design (QBD) approach from start to finish.

**This will result in:**

- **Reduction of fines** generation and **removal of contaminants** (tramp metal and rock, soil, other metallic contamination etc)
- Controlling **physical and chemical critical material attributes**
- **Managing flowability** inefficiency



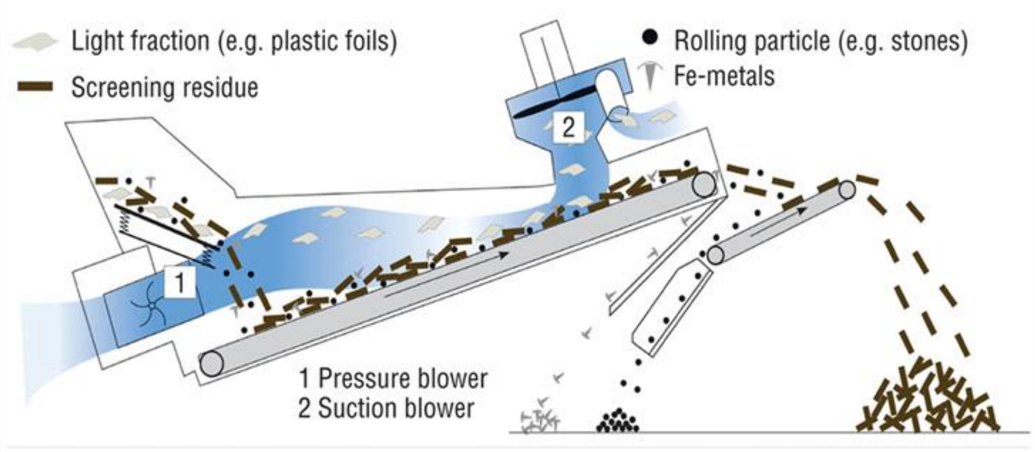
**This will be accomplished by:**

- Providing material feeding systems - **consistent feeding**
- **Screening, sorting, and separation to remove contaminants**
- **Control particle size and shape** through screening, milling, and separation practices
- Sorting and classification to **separate anatomical fractions, tissue types**, and chemical compositions
- Developing **advanced milling approaches**

# 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 industry milling operations do not address core problems** of excessive fines, contaminants, and particle size and shape differences which impact flowability challenges

- **Relevance:** Manage variability in preprocessing through:
  - Experimentally-derived interactions in material feeding
  - Sorting, screening, and separations to improve compositional critical quality attributes
  - Machine learning and automation to minimize human error
  - SOT Development
  - – FY21 Go/No-Go 30% Reduction in particle size variability, 25% reduction in ash, 30% reduction in fines
  - – Current Year Go/No-Go - Develop one new MSW derived feedstock

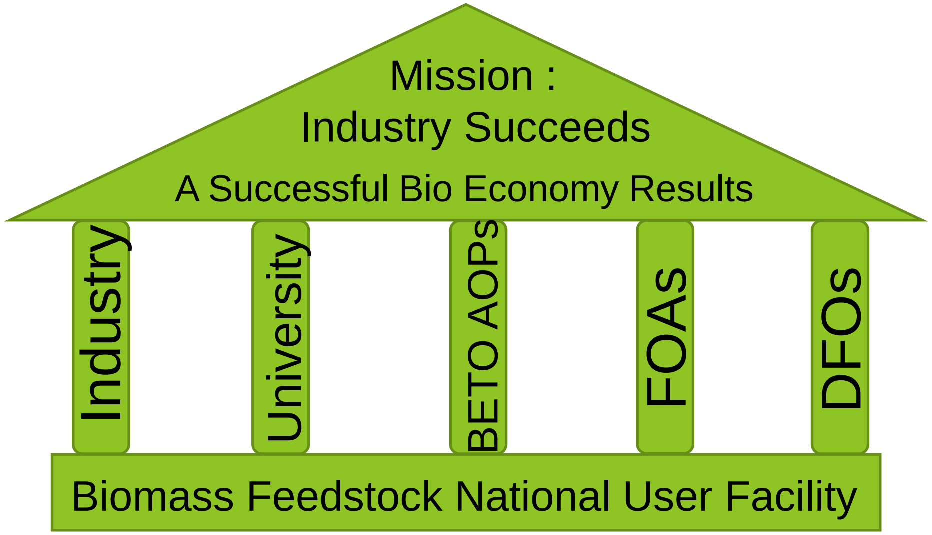



- **Risks:**
  - Multi-dimensional, multi-scale problem
  - Scale up from bench, pilot, PDU
  - Work with new waste streams like MSW (additional work control, training, etc)
  - Effective dissemination of tools and knowledge

# Project Overview

## Relevance:

- The BFNUF is the Research Engine enabling all other AOP research tasks




## Challenges:

- Must provide research opportunities to overcome challenges facing industry success – the tool must have industry compatible and scalable functionality
- Must be accessible to researchers – national labs, universities, and industry
- Coordinate experimental testing and results between research and industry

# 1- Approach

## 73 Total Projects Funded in FY22-23

| | |
|---|---|
| BFNUF Upgrade<br>• Providing Relevant SOT<br>• Advancement to the SOT | **BETO Core Projects**<br>• 25 BETO Funded Projects<br>• BETO Support to 7 National Labs |
| **BFNUF Operations AOP** | **FCIC**<br>• TASKS 1-9<br>• BETO DFOs 2 |
| **FOA Awards**<br>• 28 FOA awards | **Industry Funded Projects**<br>• 17 funded projects |

- Research staff support provide experimental design for all projects
- Fundamental learning from all programs

# 1 – Approach

## Technical Approach:

- Develop new hypothesis - **overcoming inherent feedstock variability** based on expanded experimental testing
- Develop methods based on experimental data to **achieve and predict best milling** approaches, feedstock sorting, and advanced fractionation.
- Go/No-Go based on industry partners needs, **develop a new MSW derived feedstock** for an industrial conversion partner
- 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 **current SOT**

## 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
- Demonstrate a systematic approach including product infeed, milling, sorting, and fractionation to multiple finished product lines.
- Develop new MSW derived feedstock

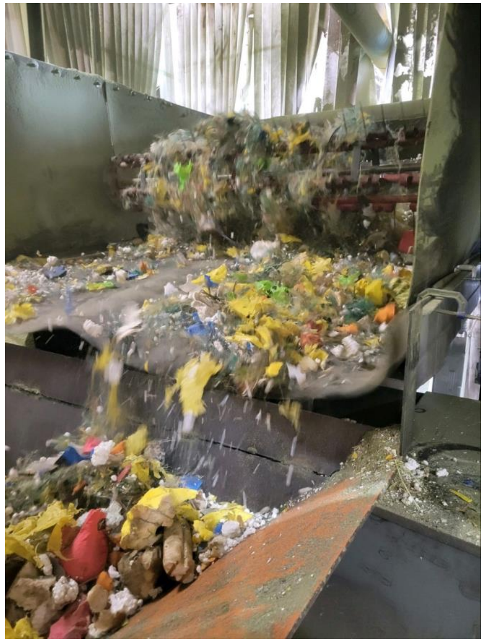
# 1 – Approach

**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 National Labs
- User Facility Projects GTI, RTI, and Titus
- Participation with lab-industry partnerships (DFO projects)
  - Fulcrum
  - Lignetics



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

# 1 – Approach

This project is managed by Neal Yancey.  It is divided into 3 main tasks presented in the table below:

| Subtask | Lead(s) | Major Responsibilities |
|---|---|---|
| **Task 1 - BFNUF User Facility Projects** | | |
| Task 1 | Luke Williams | RTI, GTI, Titus |
| **Task 2 - Feedstock Procurement and Production** | | |
| Task 2 | Neal Yancey | Feedstock Procurements and Feedstock Supply |
| **Task 3 - BFNUF Readiness and Relevance** | | |
| Task 3A | Neal Yancey | Reconfiguration |
| Task 3B | Neal Yancey | Maintenance and Upgrades |

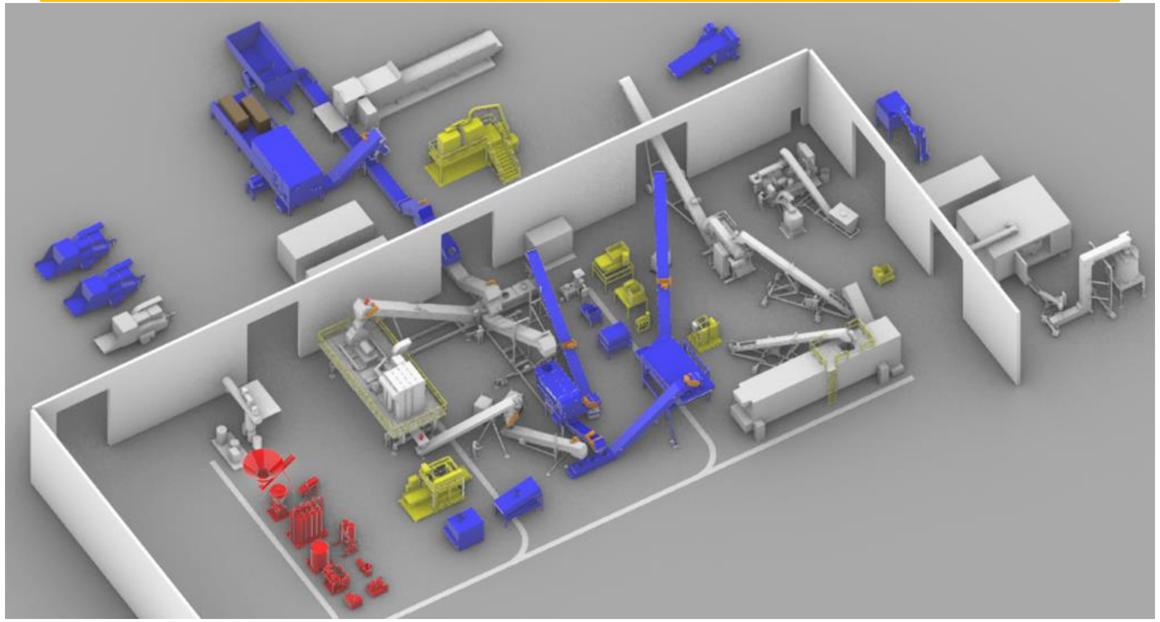
Risks:  Lack of communication between industry and laboratories; Lack of synergy between experimentation and modelers; lack of synergy between researchers at various laboratories

# 2 – Progress and Outcomes

# 2- Progress and Outcomes
# 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 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

# 2 – Progress and Outcomes

## Material Introduction

- Rock Trap and Magnetic Separator
-

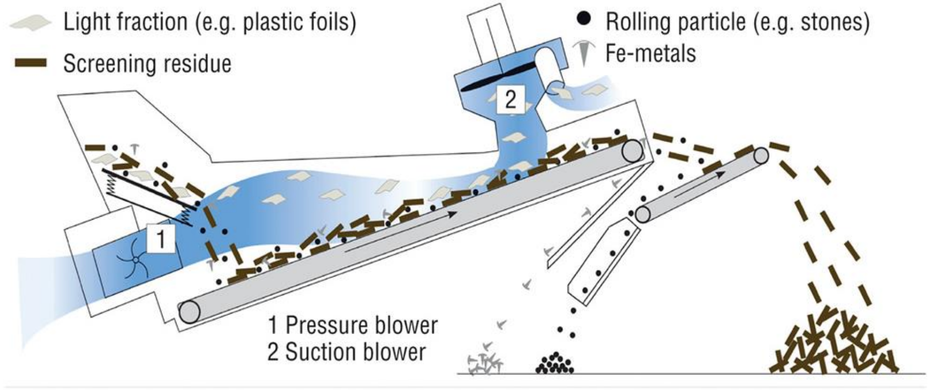
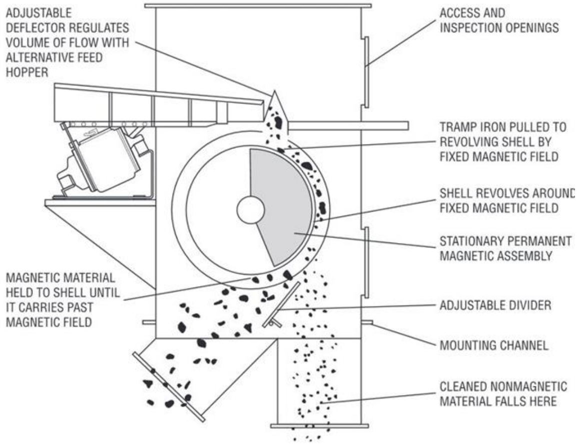


Illustration courtesy Komptech USA

Examples of foreign object in the supply material

Eddy Current Separator

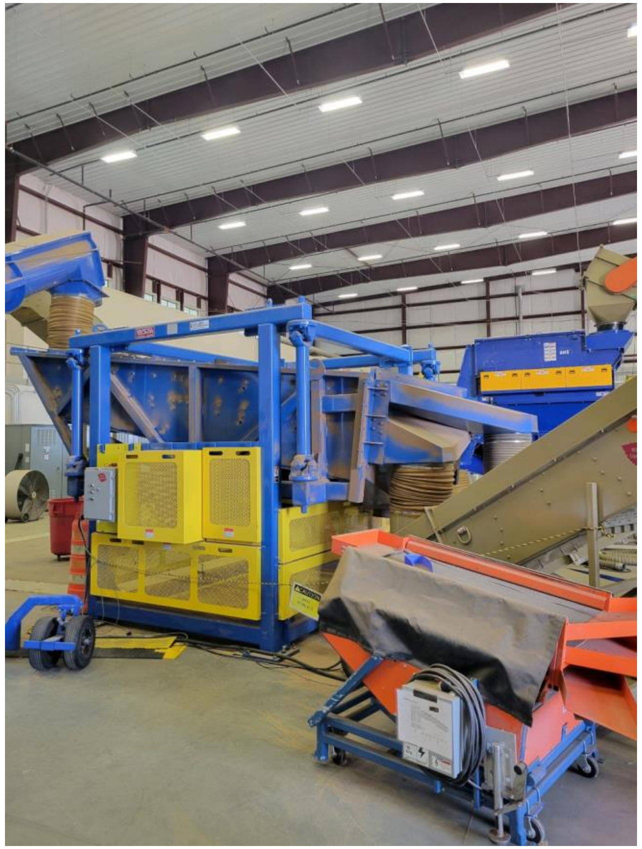
Material the current system removed




Items the current system missed

# 2 – Progress and Outcomes
# BFNUF User Facility Projects

RTI

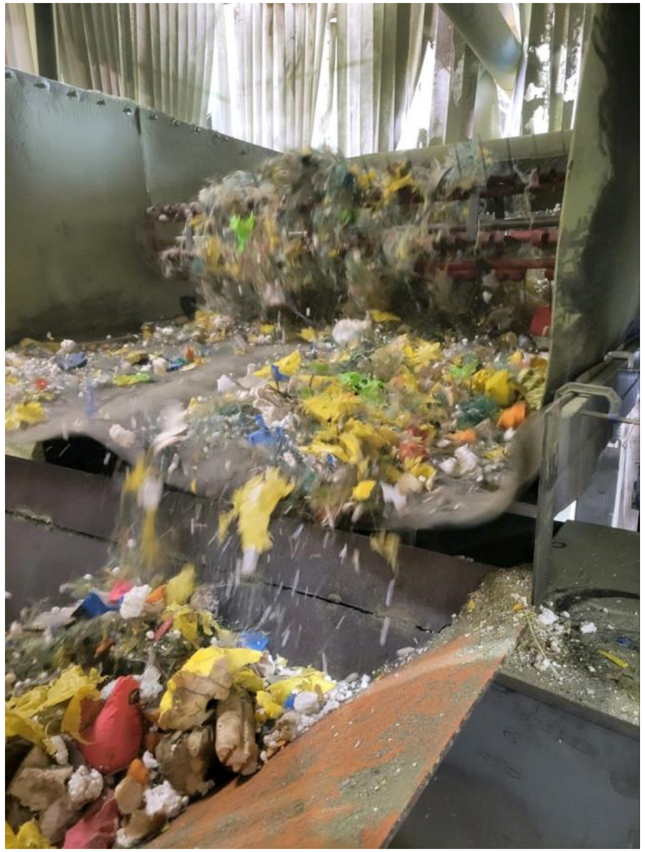


Development of consistent 1mm particles using pine and pine residue

GTI

Determination of best particle sizes and blends with corn stover and pine.  Also ability to remove ash.

Titus

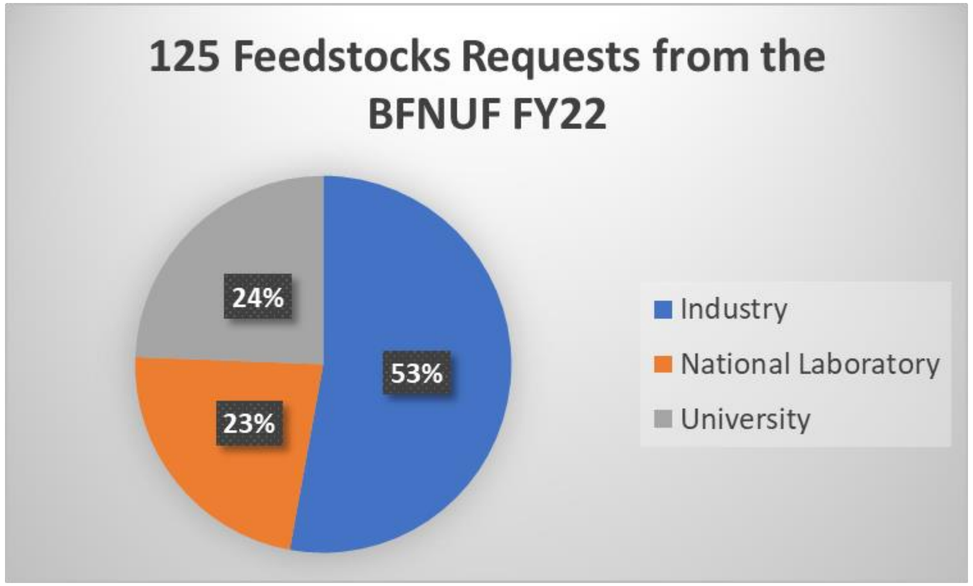


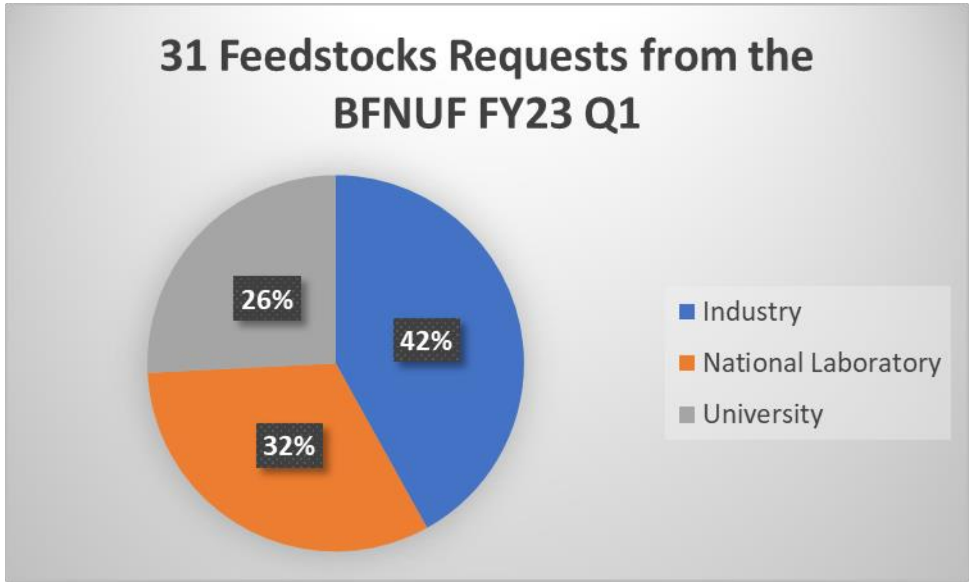
Milling, blending and densification processes for waste plastic fractions

# 2- Progress and Outcomes Feedstock Procurement and Production

Feedstocks Produced

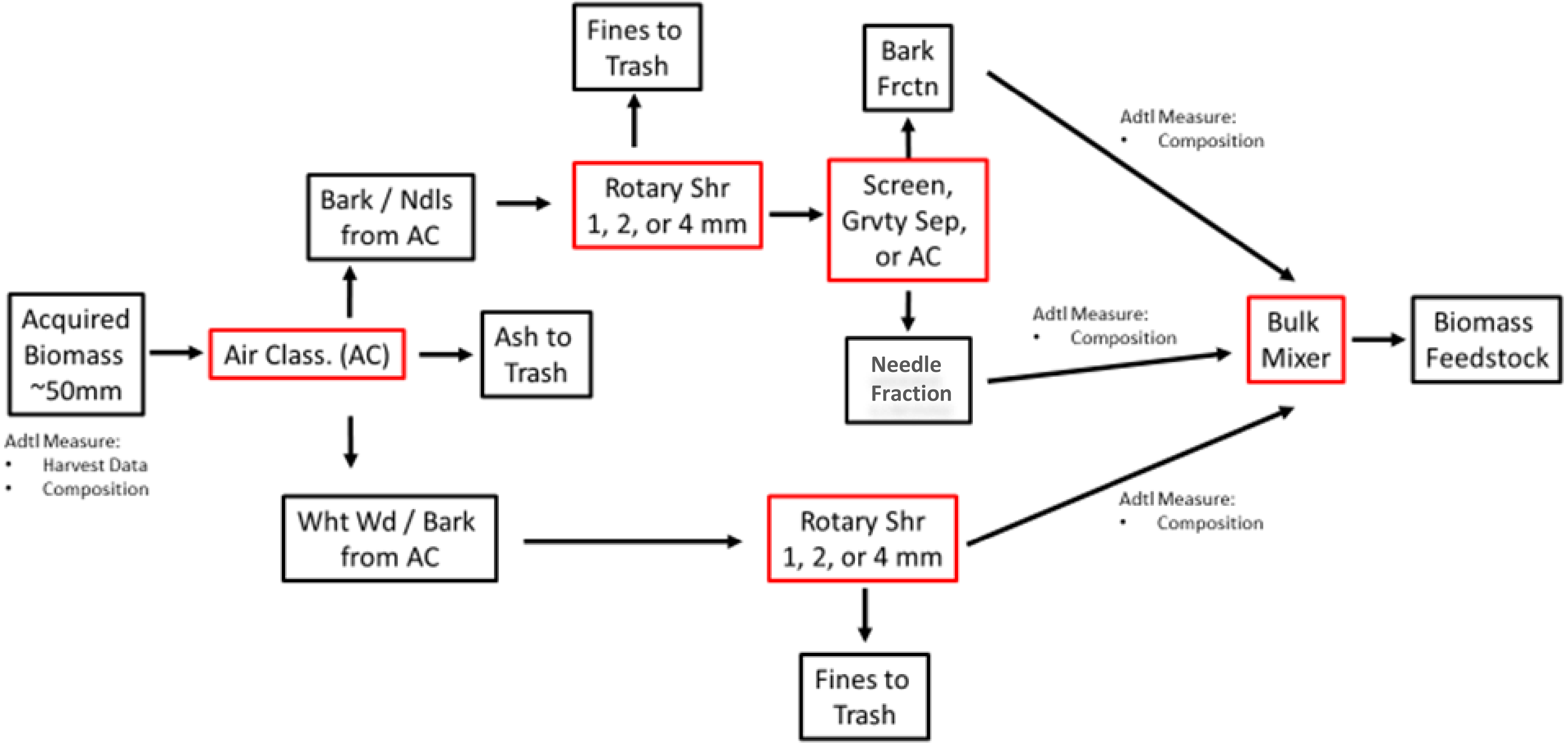
- Herbaceous – over 110 tons of feedstocks produced
  - Corn stover, switchgrass, miscanthus, sorghum, yucca, and wheat straw.
- Woody – Over 55 tons of feedstocks produced
  - Douglas Fir, hybrid poplar, loblolly pine, red oak, Chinese Tallow, red maple, sweet sorghum, birch, pastichio,
- MSW and MER waste – Over 55 tons
- E-Waste – 1500 lbs



# 2- Progress and Outcomes

# BFNUF Upgrade Improved Supplied Feedstocks



# Material Requests Feedback for 2022

**Bryon Donohoe – National Renewable Energy Laboratory**
Our systems characterize the multi-scale structure of cell walls and surface properties of particles. All of the material received worked very well in our microscopy and spectroscopy systems.

**Xiaowen Chen – National Renewable Energy Laboratory**
Biomass (corn stover) including anatomic fractions, different size from 2mm to ¾ inch. Worked very well. No challenges.

**Ajayi Oyelayo – Argonne National Laboratory**
The biomass materials are used for particle –particle and particle-wall friction measurement using high precision tribometry. In general, the friction measurements with the 6 mm particles were relatively noisy. The 2 and 4 mm particles behaved very well. The MSW material will be used for abrasive wear testing in a standard ASTM rubber-wheel sand abrasive test rig. There was a challenge with the flow of the MSW particles. A micro "plunger" was devised to improve flow of MSW to wear interface.

**Zhao Xianhui – Oakridge National Laboratory**
While compounding biomass fibers (corn stover) with polymer PLA in the shear mixer, the material mixing is smooth. One minor challenge is: during the process of adding fibers, the fine fibers can flow slightly by the flow of air at the atmosphere.

**Ning Sun – Lawrence Berkely National Laboratory**
Corn stover (self heated, anatomic fractions, etc), woody biomass. Worked pretty well. We were mainly running characterizations such as PXRD and imaging.

**Toufiq Reza – Florida Institute of Technology**
All the feedstocks received from BFNUF performed very well in our hydrothermal carbonization as well as cone calorimeter. There were no challenges related to feedstock and the quality of the feedstock.

**Dylan Cousins – Montana State University**
The different anatomical fractions showed different "areal densities" in our measurements and these densities, combined with differences in particle size, allowed us to predict differences in air classification effectiveness.

**Sheng Dai – Georgia Institute of Technology**
Basic lab characterizations (compression, deformation, shear, packing, etc.) to understand the rheology of the materials, and hopper flow testing. Major challenges include a. heterogeneity (in composition, packing, size) of the materials that lead to a wide range of properties instead of a single value, b. influencing factors to flow are too many and interwoven, c. the cause of jamming and the impacts of different equipment dimensions on the flowability are fundamentally unknown.

**Tim Saunders – Gas Technologies Institute**
We have been configuring our handling and processing system to meet the characteristics of the feedstock. We have also been adjusting the feedstock specification to improve its performance in our system. To that end our final configuration appears to meet our process needs in handling the MSW.

*full feedback provided in the additional slides

# 3 – Impact

- **Intentional material deconstruction** to maintain structure and **enable contaminant removal** and sorting
- **Customized Approach**, sorting, milling, and screening operations to achieve 3-dimensional control of particle size to improve flowability and conversion efficiency
- **Fractional milling** meets feedstock quality attributes and **increased operational and conversion efficiency** and reliability
- Subsequent **conversion operations will benefit from predictable material attributes**
- **Partnering with area an area high school supporting Diversity, Equity, and Inclusion –** supporting stem research in the area high school

## Dissemination:

### Near term:

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

### Long term:

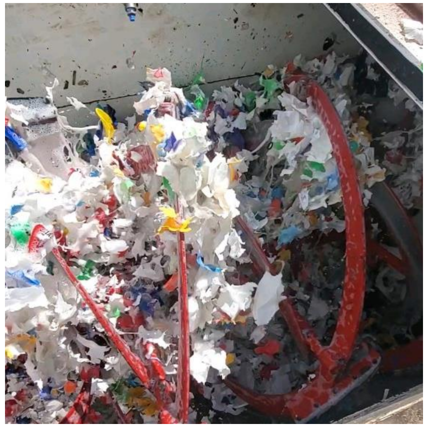
- Demonstrate industrial stakeholders
- Mitigate feedstock variability
- Partnering to bring technology to market

Municipal Waste

Agricultural Residue


Sorting

Milling



Contaminant Removal

# Summary

*This project supported 3 User Facility Industry Requests*

- *GTI*
  - *Utilized BFNUF upgrade – Forest Concepts Crumbler, JRS knife mill, West Salem oscillating screen*
  - *Produced 5 tons of woody and herbaceous feedstocks*
- *RTI*
  - *Utilized BFNUF upgrade – Forest Concepts Crumbler, JRS knife mill, West Salem oscillating screen, BHS disc screen, air classifier*
  - *Produced 10 tons of woody feedstocks*
- *Titus*
  - *Utilized BFNUF upgrade – Forest Concepts Crumbler, JRS knife mill, West Salem oscillating screen, BHS disc screen, air classifier*
  - *Produced several tons of densified plastic feedstock – ocean plastics, meat packaging waste, EFS plastics*

- *This project supported a variety of national lab, industry, and university partnerships*
  - *73 projects*
  - *Over 200 tons of processed feedstocks*
- *The project supported the current BFNUF upgrade, BFNUF operations for the 73 projects, and*
  - *Development of work control for each new upgrade*
  - *Reconfiguration for each project*
  - *Testing and development to support new approaches*

# Quad Chart Overview

## Timeline

- *10/01/2021*
- *09/30/2024*

| | FY22 Costed | Total Award |
|---|---|---|
| **DOE Funding** | *(10/01/2021 – 9/30/2022)* $1,736,996 | $6,200,000 |
| **Project Cost Share *** | | |

## TRL at Project Start: TRL 4
## TRL at Project End: TRL 5

## Project Goal

Produce feedstocks that improve downstream operational reliability and conversion yields to lower overall MFSP. Improve comminution, separations, contaminant removal and general fractionation feedstocks using BFNUF upgrade. Maintain facility readiness and operational flexibility to accommodate new feedstock requirements from national laboratory and external collaborators. Improve the ability to scale feedstock production processes from the bench to pre-pilot scale.

## End of Project Milestone

Collect data from at least 5 PI's of projects that utilized BFNUF feedstock to evaluate the impact of the feedstock on their handling and/or conversion operations. Evaluate the how the core feedstock production programs impacted external awards to improve the BFNUF's ability to attract external partners.

## Funding Mechanism

*BETO AOP*

## Project Partners*

na

*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.
- Oral Presentation: Neal Yancey. Reducing Ash and Improving Particle Size Distribution for Forest Residue Through Advanced Mechanical Preprocessing Techniques. to International Biomass Conference 2021
- Peer Reviewed Publications 1. Tumuluru, J. S., Yancey, N., and Kane, J., 2020, Grinding and briquetting characteristics of high moisture municipal solid waste bales. Waste Management.
- Tumuluru, J. S., and Fillerup, E., 2020, Briquetting characteristics of woody and herbaceous biomass blends: Impact on physical properties, chemical composition, and calorific value. Biofpr.
- Tumuluru, J. S., Fillerup, E., Kane, J. J., and Murrey, D., 2020, Advanced imaging techniques to understand the impact of process variables on the particle morphology in a corn stover pellet. Chemical Engineering Research and Design, 161, 130-145.
- Herde, Z. D., Dharmasena, R., Sumanasekera, G., Tumuluru, J. S., and Satyavolu, J., 2020, Impact of hydrolysis on surface area and energy storage applications of activated carbons produced from corn fiber and soy hulls. Carbon Resources Conversion, 3, 19-28
- Aamiri, O. B., Thilakaratne, R., Tumuluru, J. S., and Satyavolu, J., 2019, An 'in-situ binding' approach to produce torrefied biomass briquettes. Bioengineering, 6, 87.
- Pandey, R., Nahar, N., Tumuluru, J. S., and Pryor, S. W., 2019, Quantifying reductions in soaking in aqueous ammonia pretreatment severity and enzymatic hydrolysis conditions for corn stover pellets. Bioresource Technology Reports, 7, 100187.

# Additional Slides

# Material Requests – Feedback for 2022

- **Bryon Donohoe – National Renewable Energy Laboratory**

1) We received corn stover biomass in both whole, large hand-sorted anatomical fractions and ground.
2) Our systems characterize the multi-scale structure of cell walls and surface properties of particles. All of the material received worked very well in our microscopy and spectroscopy systems.
3) We had no challenges with the format received. We especially appreciate the mechanisms the BFNUF has for sorting and collecting representative samples.

- **Xiaowen Chen – National Renewable Energy Laboratory**

1) Biomass (corn stover) including anatomic fractions, different size from 2mm to ¾ inch.
2) Worked very well. No challenges.
3) Can we also get metadata from the feedstock we received? There is a ton of request for the metadata from the downstream users.

- **Ajayi Oyelayo – Argonne National Laboratory**

1) Different anatomical fractions of pine particles:- Whole; bark; needle; and stem. Three different particle sizes – 2, 4, 6 mm for each fraction. Different anatomical fractions of corn stover:- Bulk; air classified stalks; -cobs; -leaves; and –husks. 2, 4, 6 mm for each fraction. MSW – paper - 2 mm particle size
2) The biomass materials are used for particle –particle and particle-wall friction measurement using high precision tribometry. In general, the friction measurements with the 6 mm particles were relatively noisy. The 2 and 4 mm particles behaved very well. The MSW material will be used for abrasive wear testing in a standard ASTM rubber-wheel sand abrasive test rig. There was a challenge with the flow of the MSW particles. A micro "plunger" was devised to improve flow of MSW to wear interface.
3) For friction measurements, the performance of 2 and 4 mm particles for the biomass materials are adequate. For the paper-based MSW, better flowability of the particles will enable effective wear testing.

- **Zhao Xianhui – Oakridge National Laboratory**
  - 1) Switchgrass, corn stover (<0.18 mm, 0.18-0.25 mm, 0.25-0.60 mm), and pine.
  - 2) While compounding biomass fibers (corn stover) with polymer PLA in the shear mixer, the material mixing is smooth. One minor challenge is: during the process of adding fibers, the fine fibers can flow slightly by the flow of air at the atmosphere.
  - 3) The feedstock with a higher aspect ratio or surface roughness (for better fiber-matrix interface) might perform better.

# Feedback Continued

**Ning Sun – Lawrence Berkely National Laboratory**

1) Corn stover (self heated, anatomic fractions, etc), woody biomass
2) Worked pretty well. We were mainly running characterizations such as PXRD and imaging.
3) Not sure. We just need to make sure we are receiving the same materials as other national labs so that we could compare data.

**Toufiq Reza – Florida Institute of Technology**

1) Florida Tech has received both lignocellulosic and MSW from BFNUF. From the lignocellulosic biomass, we have received corn stover and loblolly pine before and after air classification. We have also received air classified MSW size 6mm , 4mm, and 2 mm on spec and corresponding rejects.
2) All the feedstocks received from BFNUF performed very well in our hydrothermal carbonization as well as cone calorimeter. There were no challenges related to feedstock and the quality of the feedstock.
3) Two main things would be the availability (so far it has been on-demand) of the feedstock and the characterization. Similar to MSDS of chemicals, if BFNUF could provide MTDS (material thermal data sheet) includes but not limited to ultimate, proximate, ash, size distribution, handling procedure, storing suggestion, and shelf life, it would be wonderful.

**Dylan Cousins – Montana State University**

1) We've received several air-classified fractions of corn stover (mostly from Story, IA). Some of it was at the bale breaker size (6" screen) while some was further processed using knife and/or hammer milling to pass 3" or 1" screens. Some of it was further milled to 2mm for composition/EH experiments.
2) The different anatomical fractions showed different “areal densities” in our measurements and these densities, combined with differences in particle size, allowed us to predict differences in air classification effectiveness.
3) The feedstocks provided worked well for our studies and similar methods could be used to advance our study of air classification for other materials in the future.

**Sheng Dai – Georgia Institute of Technology**

1) Both biomass and MSW. Biomass: loblolly pine chips, sieved, low ash low moist. MSW: both original stream and 5 fractions (paper, cardboard, thin film, rigid plastics, and foam), in 2mm, 4mm, and 6mm sizes.
2) Basic lab characterizations (compression, deformation, shear, packing, etc.) to understand the rheology of the materials, and hopper flow testing.

   Major challenges include a. heterogeneity (in composition, packing, size) of the materials that lead to a wide range of properties instead of a single value, b. influencing factors to flow are too many and interwoven, c. the cause of jamming and the impacts of different equipment dimensions on the flowability are fundamentally unknown.

1) Thorough understanding of major influencing factors and quantifying their impacts on feedstock behavior; b. Enhanced material characterization and preparation methods, identify and establish the protocols for material preparation and testing standards; c. Develop guidelines for feedstock handling equipment design and modification.

**Tim Saunders – Gas Technologies Institute**

1) Non-recoverable municipal solid waste (nMSW) from Waste Management, Salt Lake City MRF.
2) We have been configuring our handling and processing system to meet the characteristics of the feedstock. We have also been adjusting the feedstock specification to improve its performance in our system. To that end our final configuration appears to meet our process needs in handling the MSW.
3) Our program is evaluating the feedstock for handling characteristics that match our system needs and then identifying processing and constituent component changes to enhance performance. Once selected, consistent specification in the feedstock supplied will be critical.