April 5, 2023

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WBS 1.2.1.2 Biomass Size Reduction, Drying and Densification

Technical Area Session: Feedstock Technologies Program

DOE Bioenergy Technologies Office (BETO) 2023 Project Peer Review

Project Overview

Challenges and Limitations: Low-cost carbon resources (agricultural residues, forest residue, and non recyclable municipal and industrial wastes) exhibit consistent challenges. **Inherent physical and chemical variability** in feedstocks **result in excessive process downtime, and uncontrolled costs** with documented failures in the industry as a whole. Common industry milling operations do not address core problems such as: fines, contaminants, and particle size and shape differences which impact conversion efficiency and handling:

- Low bulk density and poor flowability characteristics
- Highly variable critical physical characteristics including moisture, ash content, and particle size/shape
- Highly variable chemical composition – significantly impacting conversion efficiency
- Presence of undesirable contaminants – rocks, tramp metal, dirt, etc.

The Impact:

- **Significant downtime** during preprocessing and feeding
- **Excessive wear**
- Plugging of conveyors and hopper
- **Inability to control particle size** and the generation of fines
- Poor conversion efficiency

Project Overview (cont.)

- **Relevance:** Manage variability in preprocessing operations through:
  - **Experimentally-derived interactions** in material feeding
  - **Sorting, screening, and separations** to improve compositional critical quality attributes
  - **Digital Modeling**
  - **State of Technology Development**
- **Risks:**
  - Multi-dimensional, multi-scale problem
  - **Scale up from Bench, Pilot, Process Development Scale, Industry Scale**
  - Timely adaptation of preprocessing equipment for maximum impact
  - Effective dissemination of tools and knowledge for maximum market impact

1 – Approach

Subtask	Lead(s)	Major Responsibilities
Task 1 - Fractionation and Milling of Corn Stover and Municipal Solid Waste		
Task Lead	Neal Yancey	
Task 2 - Densification of Corn Stover and Municipal Solid Waste Fractions		
Task Lead	Zachary Smith	
Task 3 - Characterization of Corn Stover and Municipal Solid Waste Fractions		
Task Lead	Mark Small	
Task 4 - Digital Twin Modeling		
Task Lead	Yidong Xia	
Task 5 - Low Temperature Drying Studies		
Task Lead	Zachary Smith	
Task 6 - Technical Economic Analysis and Life Cycle Analysis		
Task Lead	Yingqian Lin	

Risks, Lack of:

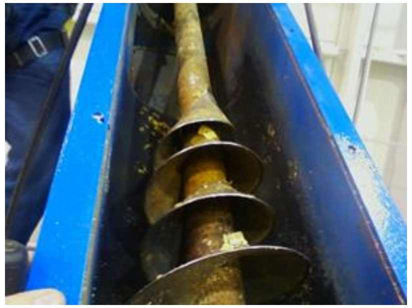
- Communication between industry and laboratories
- Synergy between experimentation and modelers
- Synergy between researchers at various laboratories

2 – Process and Outcomes - Fractionation and Milling

Historical Single or Dual Stage Milling

High Aspect Ratio

Plugged Conveyors



Damaged Equipment

Inconsistent Material

2 – Process and Outcomes - Fractionation and Milling

Minimal Up-front Size Reduction

Screen and Sorting as need

Material Specific Milling

Uniform Physical and Chemical Properties

Predictable and Manageable Flow

High Quality Consistent Final Product

This project uses a quality by design approach to consistently meet physical and chemical quality attributes

2 – Process and Outcomes - Fractionation and Milling (cont.)

Low Speed Low Energy Bale Processor Enables:

- downstream fractionation
- contaminant removal

2 – Progress and Outcomes - Fractionation and Milling (cont.)

Woody Waste

White wood

Bark

Needles

Municipal Waste

Paper

Cardboard

Film Plastics

Hard Plastic

Ag Residue

Cobs

Stalks

Leaves

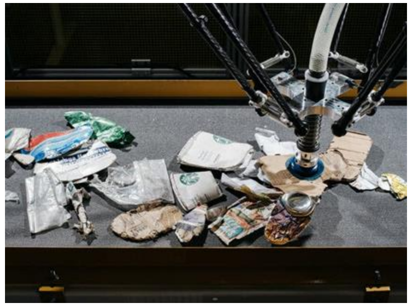
Husks

BFNUF Upgrades Enable Fractionation

Mechanical Screening

Air and Density Separation

Robotic Separation



2 – Progress and Outcomes - Fractionation and Milling (cont.)

Cardboard | Paper | Film Plastic | Hard Plastic

Crumbled MSW Fractions

Cardboard | Paper | Film Plastic | Hard Plastic

Hammer Milled MSW Fractions

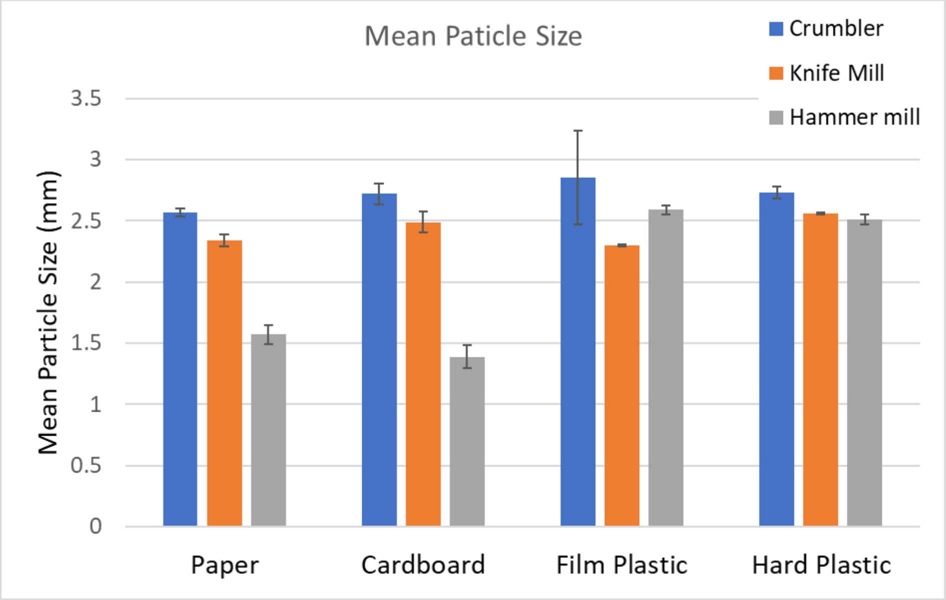
Cardboard | Paper | Film Plastic | Hard Plastic

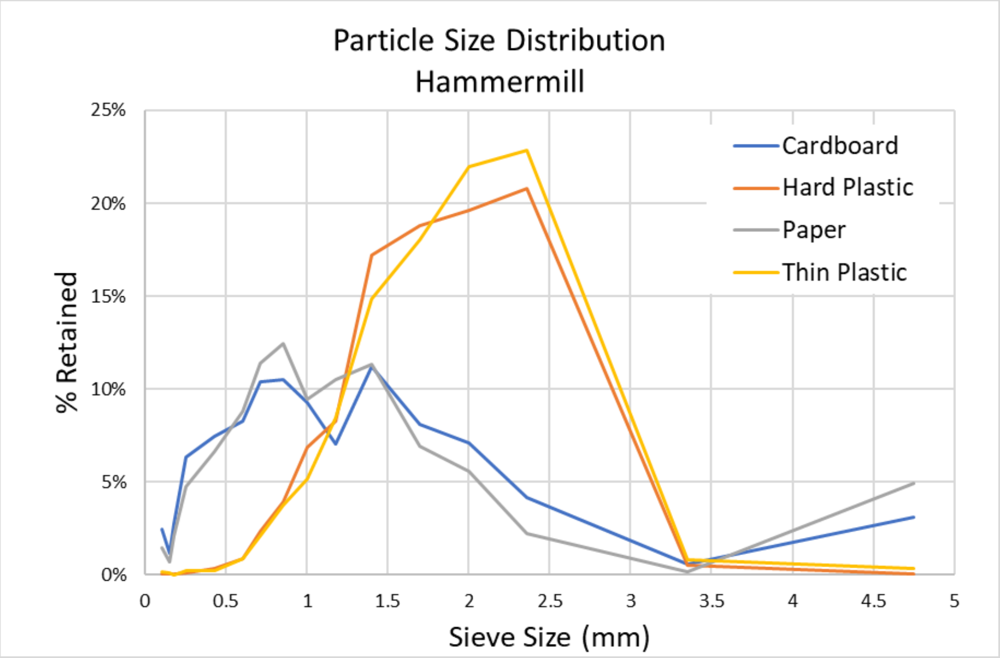
Knife Milled MSW Fractions

2 – Progress and Outcomes: - Fractionation and Milling (cont.)

JRS Knife Mill

Particle size data was compared between the milling approaches



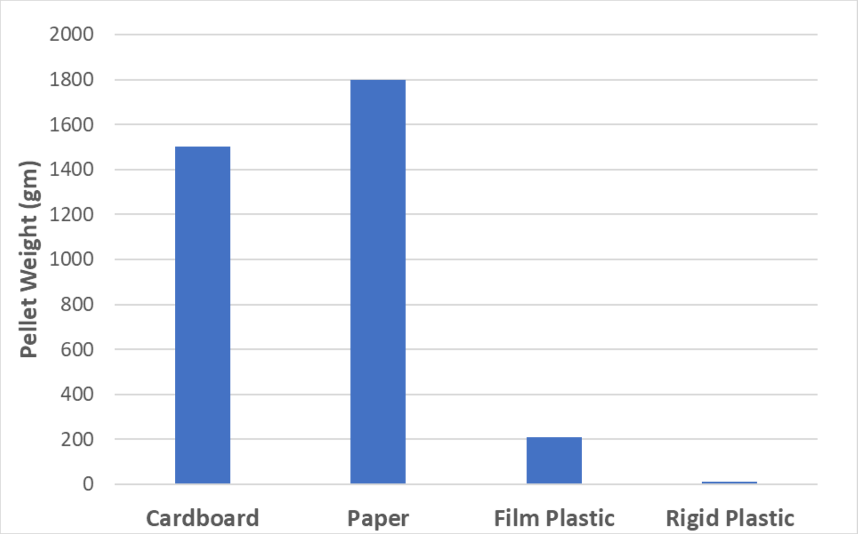


Comparing particle size distributions differences in MSW fractions

2 – Progress and Outcomes: - Densification

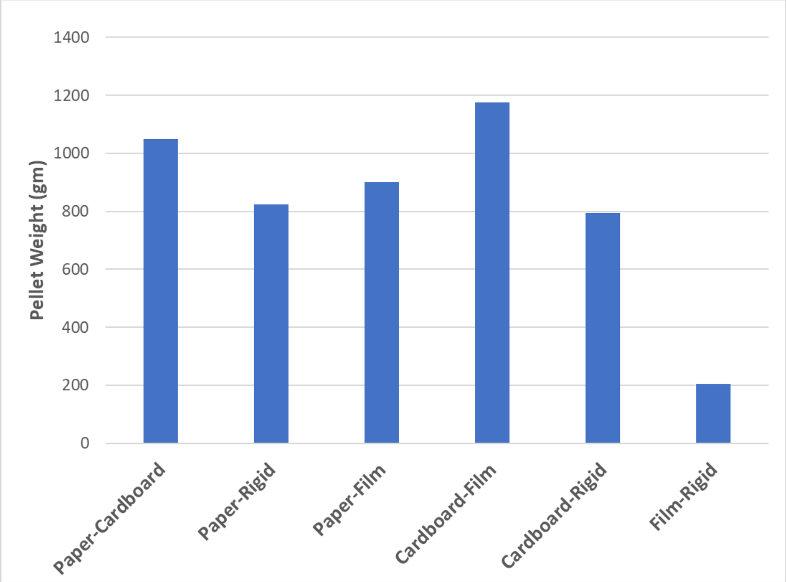
Started with 2000 grams initial mass

- Weights shown represent the amount of material that was successfully pelleted
- Plastics alone did not pellet well under the conditions tested



Started with 1200 grams initial mass

- Weights shown represent the amount of material that was successfully pelleted
- When blended with paper or cardboard, plastics do form pellets



Densified Paper

Densified Cardboard

Densified Film Plastic

2 – Progress and Outcomes: - Densification cont.

100% Hard plastic extruded pellets

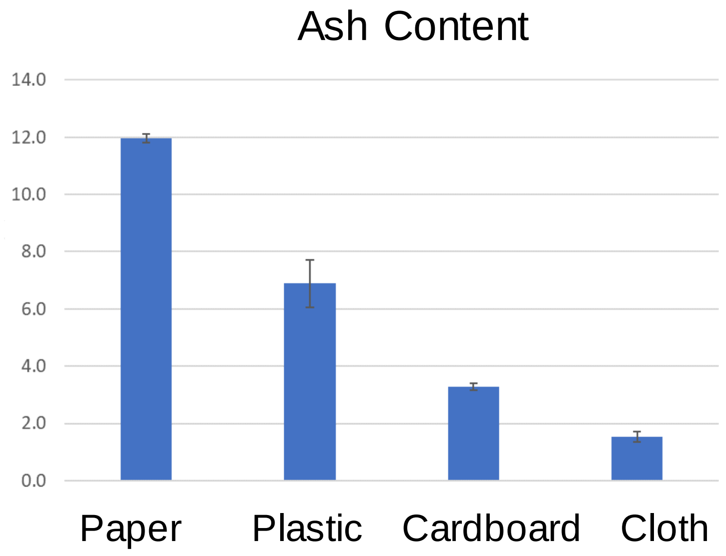
100% Film plastic extruded pellets

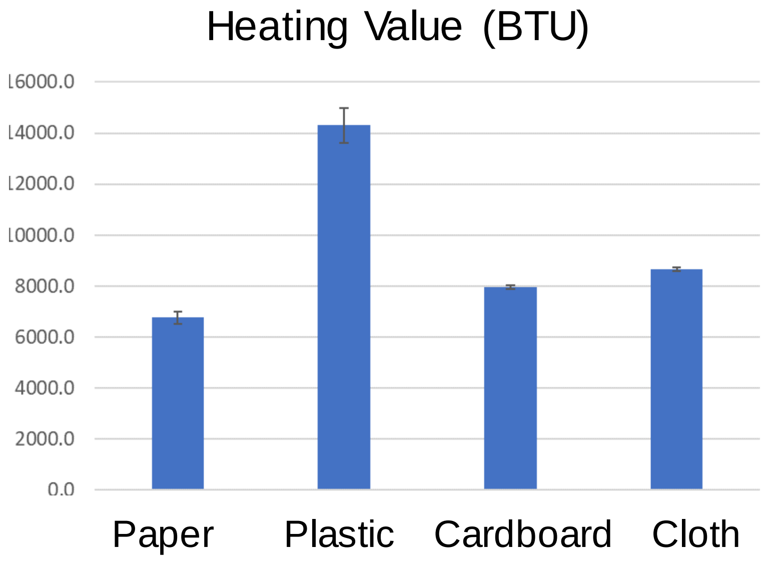
2 – Progress and Outcomes: - Characterization cont.

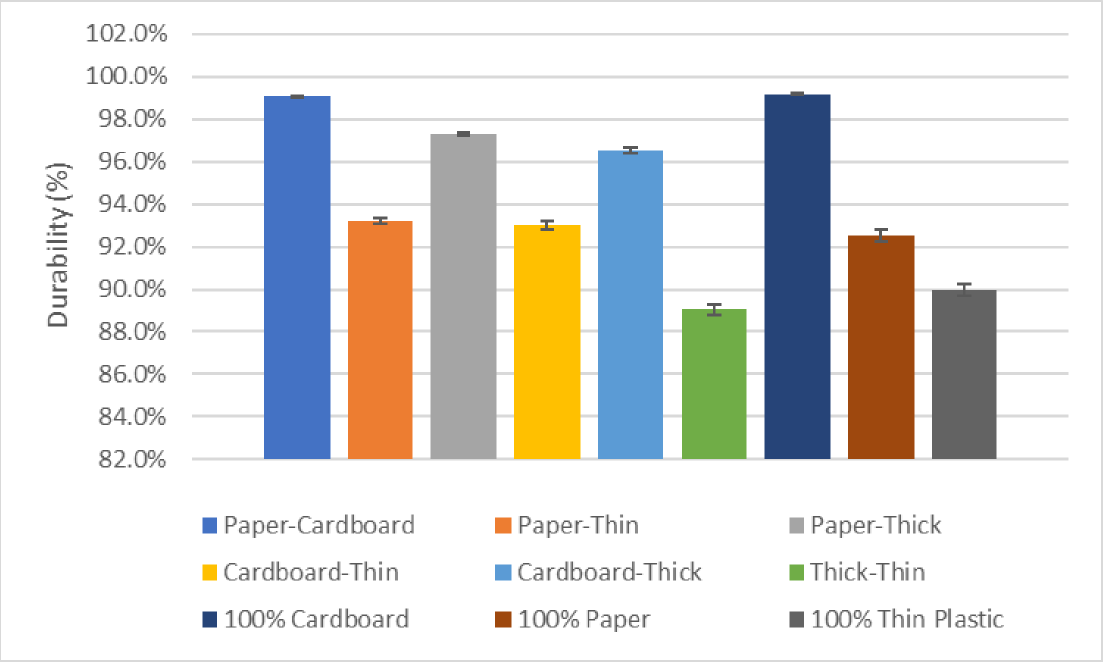
Understanding the differences in chemical composition of each fraction supports the concept of blending to achieve a consistent composition prior to conversion:

Physical Analysis
- Particle Size
- Bulk Density
- Moisture

Chemical Analysis
- Extractives
- Elemental Analysis
- Ash
- Heating Value
- Sugars
- Lignin
- Carbon





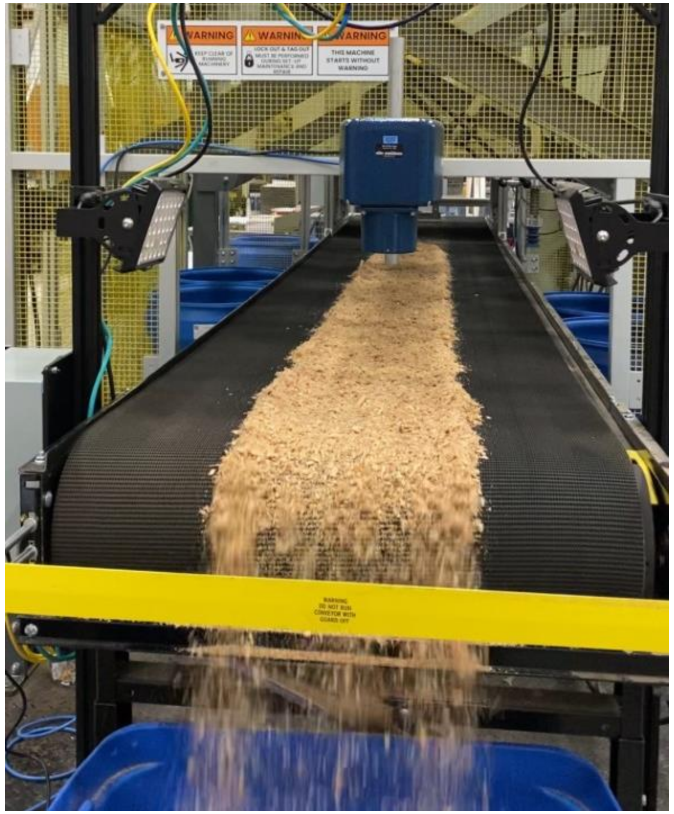


Mass Fractions
- Anatomical Fraction
- Tissue Fractions
- MSW – Paper/ Plastic /Cardboard/Inorganics

2 – Progress and Outcomes: - Characterization

Developing Applications for Inline Sensors

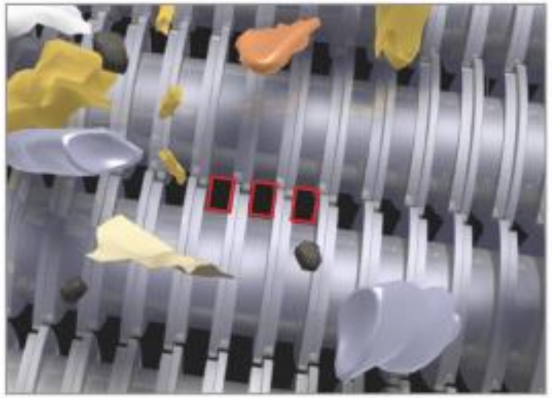
In-line Particle Size Sensor



In-line Moisture Sensor

2- Progress and Outcomes - Digital Twin Modeling

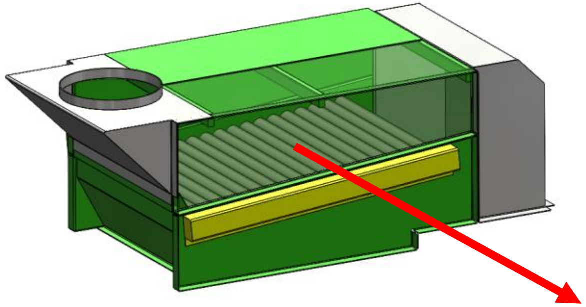
Patented Bulk Handling System (BHS) compound discs are in-line from shaft-to-shaft creating a precise opening for highly accurate material sizing. The unique, patented discs provide excellent material agitation and separation.



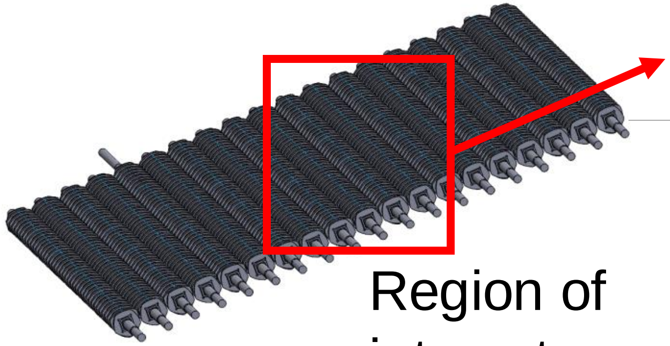
Digital Twin Goal – from "high-fidelity, low speed" to "high-predictability, high speed"

Status:

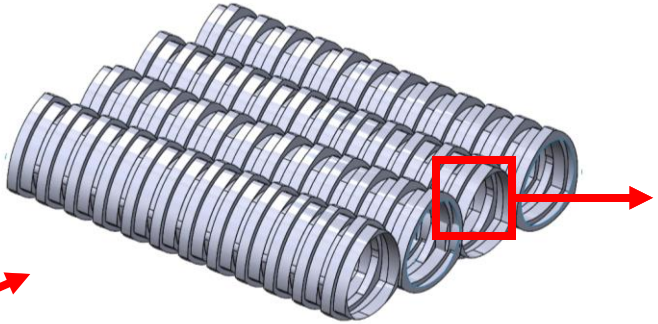
- Simplified CAD model has been developed
- CAD model is being used to create Multi-Physics Simulation



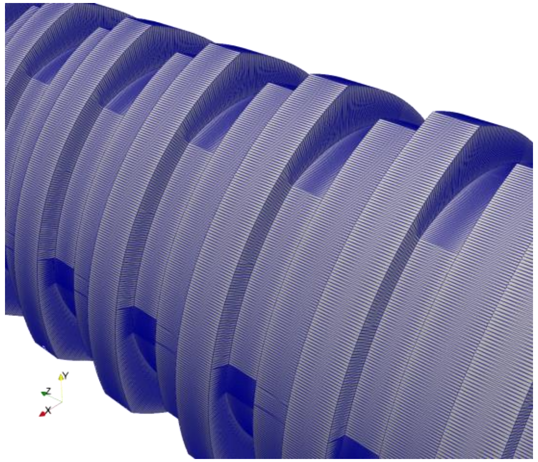
Vendor's CAD (received under NDA)



Region of interest

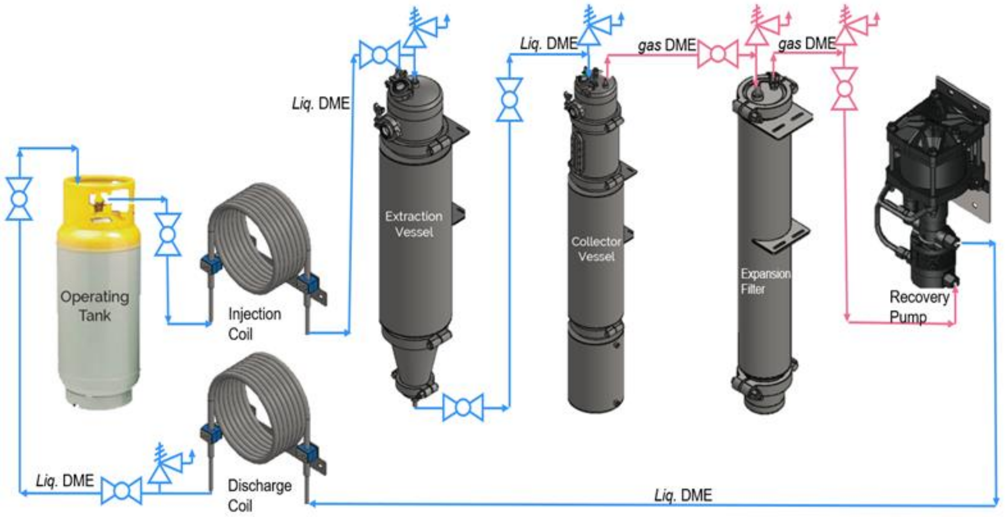


Modeling-adapted CAD



Surface mesh

2- Progress and Outcomes - Low Temperature Drying



Chemical Dewatering

- Effective for difficult to remove moisture

Mechanical Dewatering

- Effective at separating surface or light to moderately bound water

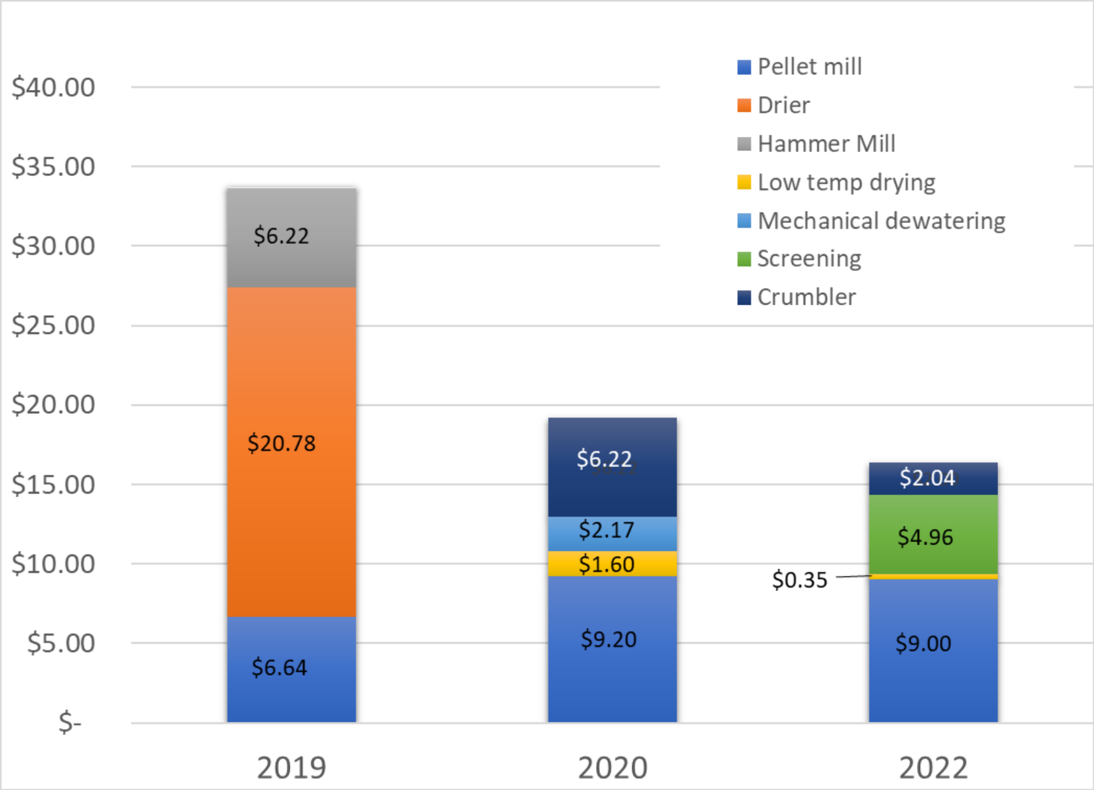
Low Temperature Grain Driers

- Very effective at removing residual moisture – following high moisture densification

2- Progress and Outcomes: - Technical Economic Analysis

Reduced Processing Costs through high moisture processing and pelleting and low temperature drying

- 2019 - $33.64
- 2020 - $19.19
- 2022 - $16.35



3 – Impact

- This project specifically **addresses a recognized barrier such as the generation of fines** in feedstock preprocessing, which effects the downstream conversion yields and supports the bioeconomy.
- **Converts diverse forms of herbaceous and low-cost carbon resources** into a consistent, high-quality commodity product to efficiently store, feed, handle, and transport to biorefineries.
- The outcomes **specifically addresses biomass variability issues** during preprocessing.
- Preprocessing technologies developed **can be used by biomass processors and designers** for producing biofuels, chemicals, and bioproducts.
- Helps to **achieve DOE's vision of commoditization** of diverse forms of biomass at a lower cost.

Summary

Reducing and Removing Variability in Low Value Carbon Feedstocks

- ***Advanced Milling and Separation***
  - ***Removing High Speed Bale Grinding***
    - ***Lower energy -*** Reduced the energy consumption by 25%
    - ***Enables Contaminant Removal***
    - ***Supports Down screening and separations***
  - ***Screen and Sorting***
    - ***Remove soil, rocks, and tramp metal -***Total ash reduction from 2.62% to 1.02%
    - ***Separation of tissue rich (stalks, cobs, leaves) or material types in MSW -*** 75% reduction in non-whitewood fraction
- ***Densification***
  - ***High moisture Densification – reduces overall cost***
  - ***Blending to achieve successful product quality***
- ***Characterization***
  - ***Understanding quality metrics***
  - ***Development and implementation of inline sensors***
- ***Digital Modeling***
  - ***Ties fundamental research to operational parameters***
- ***Low Temperature Drying –*** Reduces overall costs
- ***TEA Development***

Quad Chart Overview

Timeline

- *10/01/2020*
- *09/30/2023*

	FY22 Costed	Total Award
DOE Funding	*$913,224*	*$2,299,000*
Project Cost Share *		

TRL at Project Start:3
TRL at Project End:4

Project Goal

Optimize the preprocessing systems (rotary shear, hammer milling and knife mill grinding, dewatering, and densification) for low-cost carbon resources such as blends of forest residue + MSW plastic fractions to meet the critical quality attribute, such as particle size, density, and moisture content. Conduct TEA and LCA analysis to show reduction of 40% of preprocessing cost and 40% of greenhouse gas emissions compared to the conventional methods followed by industry.

End of Project Milestone

Conduct pelleting studies on each process condition for corn stover and MSW (4 fractions). Successfully hit the pelleting targets at least one of the CS MSW blended pellets to achieve 300 kg/m^3 bulk density, a bulk porosity of about 70%, and a moisture content of < 10% (w.b.). Conduct TEA/LCA of the new preprocessing technologies and show a reduction of 30% in preprocessing cost and 40% reduction in GHG emissions based on the current preprocessing methods followed by the industry.

Funding Mechanism

AOP WBS #1.2.1.2

Project Partners

na

*Only fill out if applicable.

Idaho National Laboratory

Battelle Energy Alliance manages INL for the U.S. Department of Energy's Office of Nuclear Energy. INL is the nation's center for nuclear energy research and development, and also performs research in each of DOE's strategic goal areas: energy, national security, science and the environment.

Additional Slides

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. *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.
- Books published 1. Tumuluru, J. S. (2021). Biomass densification: Systems, methods, process conditions, quality attributes, and conversion performance" has been accepted by Springer for publication.
- Tumuluru, J. S. (Ed.)., (2021). Woody Biomass for Bioenergy Production, Energies, MDPI publications (In press) Guest Editor for Special Issues 1. Energies Journal: Municipal Solid Waste Logistics and Conversion to Produce Biofuels and Bioproducts (editor: Jaya Shankar Tumuluru).
- Frontiers in Energy Research: Torrefaction Pretreatment for Biomass Upgrading: Fundamentals and Technologies (Editors: Paola Brachi, Wei-Hsin Chen, Daya Ram Nhuchhen, and Jaya Shankar Tumuluru).

- 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. (https://onlinelibrary.wiley.com/doi/abs/10.1002/bbb.2121).
- 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.

Patent 1. Jaya Shankar Tumuluru. Systems and methods of forming densified biomass. US14324902 (Pending). Awards High moisture pelleting is an R&D 100 Award finalist in the year 2020.

Dr. Tumuluru received Idaho National Laboratory's exceptional engineering achievement award in 2020. Conference Organizing Committee & Bioproducts Conference (IBBC) International Bioenergy & Bioproducts Conference (IBBC-2020)

Conference secretary. Moderated technical sessions for American Society of Agricultural and Biological Engineers. Energy Systems, Vice-Chair, for American Society of Agricultural and Biological Engineers.