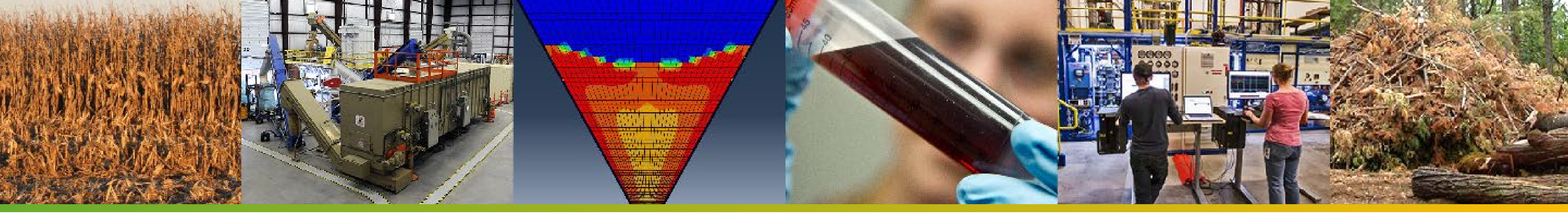


DOE Bioenergy Technologies Office (BETO) 2021 Project Peer Review

FCIC DFO – Moisture Management and Optimization in Municipal Solid Waste Feedstock through Mechanical Processing

Date: 03/16/2021
Technology Area Session: FCIC

Lead: Mujinga Mwamufiya (Task Lead), Fulcrum BioEnergy, Inc.
Presenter: Jaya Shankar Tumuluru (Task Co-Lead), Idaho National Laboratory

fcic
FEEDSTOCK-CONVERSION INTERFACE CONSORTIUM

FCIC Task Organization

FCIC
FEEDSTOCK-CONVERSION INTERFACE CONSORTIUM

Feedstock → **Preprocessing** → **Conversion**

Feedstock Variability:
Develop tools that quantify & **understand the sources of biomass resource and feedstock variability**

Preprocessing:
Develop tools to enable technologies that **provide well-defined and homogeneous feedstock** from variable biomass resources

Conversion (High & Low-Temperature Pathways):
Develop tools to enable technologies that **produce homogeneous intermediates** that can be converted into market-ready products

Materials Handling:
Develop tools that enable continuous, steady, trouble-free feed into reactors

Materials of Construction:
Develop tools that **specify materials** that do not corrode, wear, or break at unacceptable rates

Enabling Tasks

Data Integration: Ensure the data generated in the FCIC are **curated and stored** – FAIR guidelines

Crosscutting Analyses TEA/LCA:
Works with other Tasks to **enable valuation** and intermediate streams, and quantify impact of variability

Project Overview

MSW feedstock: Municipal solid waste (MSW), commonly referred to as garbage in the U.S., consists of product packaging, grass clippings, furniture, clothing, bottles, food scraps, newspapers, appliances, paint, and batteries. The organic material in MSW, which is rich in hydrogen and carbon, can be used for biofuels production.

Fulcrum Bioenergy

- Fulcrum successfully developed and demonstrated a process for converting MSW organic material into transportation fuels using clean and efficient gasification and the Fischer-Tropsch process
- The process has been demonstrated and proven on an integrated basis at scale.

MSW Challenges

a) High moisture, variable particle size and shape, and low bulk density creates feeding, handling, storage, and transportation issues; and b) High temperature drying systems can result in volatile organic compound (VOC~~s~~) emissions.

Densification

Produces a uniform commodity type product with a) definite size, shape, and density b) increases the bulk density of the material by about 5-10 times c) reduces the moisture content to <10 % (w.b.) and (d) improves the feeding, handling, and storage characteristics, and transportation efficiencies.

Challenge: Cost of MSW preprocessing using conventional technologies followed by the industry.

Project Overview

Objective

The overall objective of this project is to develop mechanical preprocessing technologies to manage moisture efficiently in MSW. The specific objective is to increase MSW density and reduce moisture to meet gasifier infeed requirements (e.g., moisture of ~10%, bulk density ~ 480 kg/m^3 and durability >95%), while reducing the preprocessing cost by 40% as compared to the conventional pelleting method.

Relevance:

- This project addresses a real problem for Fulcrum and, if successful, will be a part of the design of future biorefinery feedstock processing.
- This project advances the understanding of biomass-derived feedstock properties, in support of FCIC's 90% operational reliability target.
- This project furthers the DOE/BETO objective of optimizing biomass feeding and handling systems in the biofuels industry.
- Moisture management and density solutions developed in this project can be applied to other herbaceous and woody feedstocks.

1 – Management

Management Approach

- DOE, Merit Review in 2019
- Biweekly call with Fulcrum to discuss project progress
- Major milestones with definite quality, cost targets, and Go/No-Go decision point
- Work with INL analysis team to update the state of technology costs based on the results obtained in this project
- Present the results in FCIC quarterly and annual meeting and DOE peer review.

Critical success factors: Optimize the mechanical preprocessing technologies to produce MSW with the desired density, durability, and moisture content.

Team

Fulcrum Bioenergy: Mujinga Mwamufiya (Director, Business Development), Gregor Thomson (Technical Manager), and Sam Butler (Project Engineer)

Idaho National Laboratory: Jaya Shankar Tumuluru (Staff Engineer), Neal Yancey (Lead Engineer, BUFNUF), Damon Hartley (Lead, Analyst), Yingqian Lin (Tammy)(Analyst), and Zach Smith (Research Engineer)

Risks: (1) MSW is heterogenous in nature and can behave differently compared to other biomass; (2) MSW has an unknown effectiveness on key operational parameters (e.g., moisture reduction, system efficiency, reliability); and (3) MSW feedstock introduces high wear and tear in the processing equipment.

Mitigation: (a) Tests are conducted by varying the grinding and pelleting process variables to understand their relationship to quality and energy consumption; and (b) to address some wear issues, both the hammer mill and pellet mill are equipped with magnetic traps to stop the metal entering the equipment.

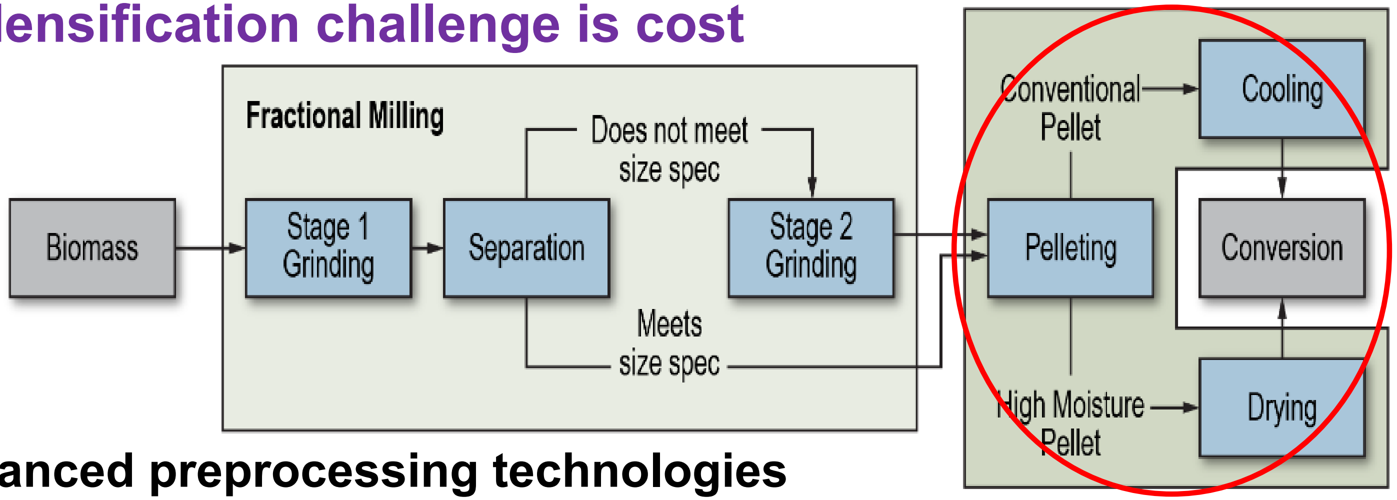
2 – Approach

Fractional milling:
- Stage-1 grinder screen size is increased, and a separator is inserted between the stage-1 & 2 grinders to bypass the fraction that meets the stage-2 grinder specs.
- Eliminates biomass overgrinding and results in tighter particle size distribution.

High moisture pelleting:
- Biomass is pelleted at >20% (w.b.) moistures.
- Biomass loses moisture (5-10%, w.b.) during pelleting.
- Eliminates energy-intensive rotary drying step.

Low temperature drying
- Grain or belt dryers to dry high-moisture pellets.
- Eliminates VOC emissions.

Conventional densification challenge is cost



Advanced preprocessing technologies developed by INL.

This process was tested on corn stover bales at about 25% moisture and has reduced the pellet production cost by 60% compared to the conventional method followed by industry.

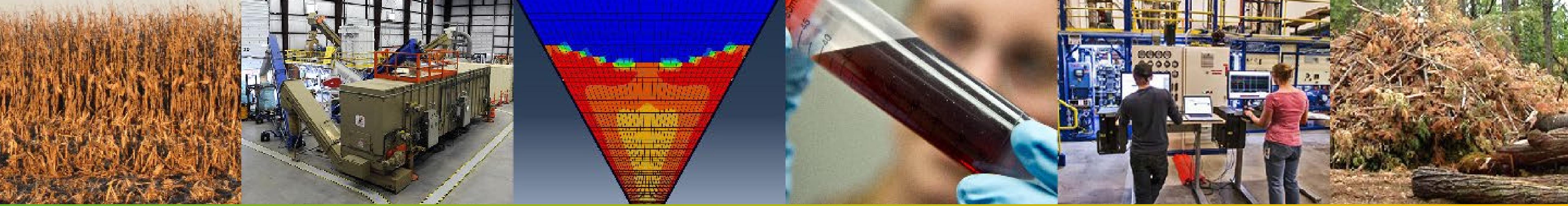
Use novel preprocessing technologies to address MSW moisture and density challenges

Quality of corn stover pellets

3 – Impact

- This project addresses recognized barriers, such as: (a) variability in particle size; (b) moisture; and (c) low bulk density, which affects feeding, handling, and transportation issues for thermochemical conversions, and thus, the bioeconomy.
- Achieve DOE's vision of biomass commoditization at a lower cost.
- Convert diverse forms of biomass into consistent, high-quality commodity products, and will help to efficiently handle, store, and transport the biomass to biorefineries.
- The preprocessing solutions developed in this project can be transferred to 2nd generation biorefineries to improve operational reliability, and potentially make pelleting a more cost-effective option in the U.S.
- This project addresses MYPP barriers:
  - ❑ Ft-G: Feedstock Quality & Monitoring
  - ❑ Ft-K: Biomass Physical State Alteration
  - ❑ Ft-L: Biomass Material Handling and Transportation
  - ❑ Ft-I: Overall integration and scale-up.

High moisture pelleting was an R&D Award finalist in FY-2018 and FY-2020



4 – Progress and Outcomes

Grinding studies

1-inch MSW grind received from Fulcrum was conditioned to 25 and 30 % (w.b.) moisture and is used for grinding studies in a hammer mill

1/4-inch MSW

MSW grind properties processed through the Fulcrum shredders

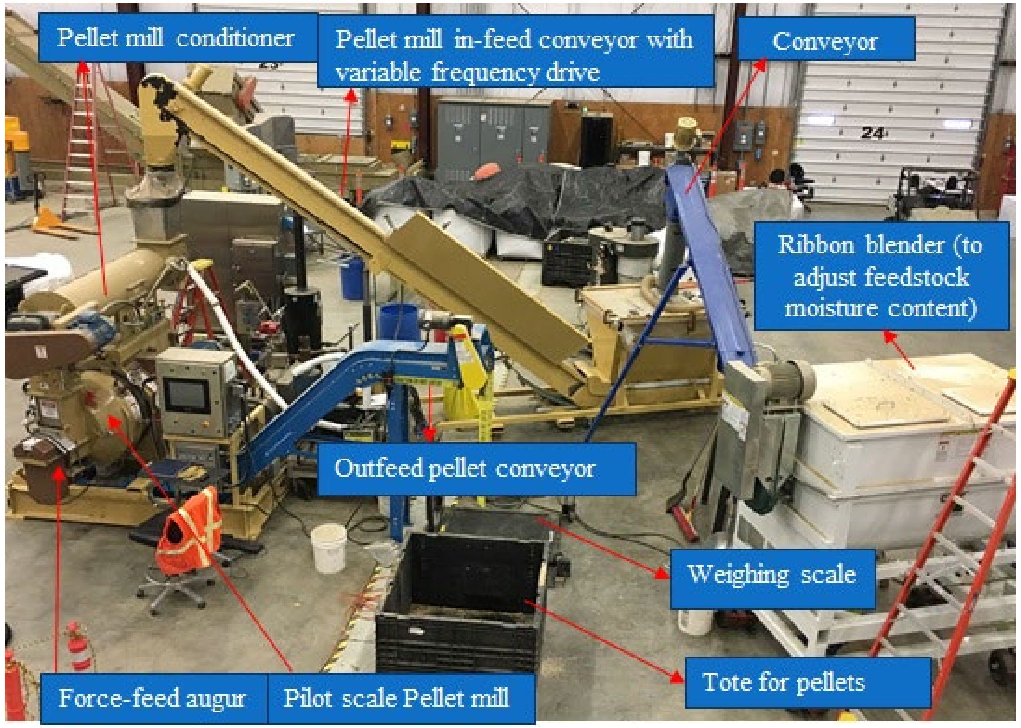
		Before grinding				
MSW grind size	MSW moisture (%, w.b.)	D10 (mm)	D50 (mm)	D90 (mm)	Xgm (mm)	Bulk density (kg/m^3)
1-inch (25.4 mm) received from Fulcrum	30.4	1.77	13.5	27	9.37	55.5

MSW grind properties processed through INL Hammer mill

Hammer mill	**MSW moisture (%, w.b.)**	**D10 (mm)**	**D50 (mm)**	**D90 (mm)**	**Xgm (mm)**	**Bulk density (kg/m^3)**	**Grinding energy (kWh/ton)**
1/4inch (6.35 mm)	13.45	0.20	1.78	5.45	2.38	50.21	136.89
1/2-inch (12.7 mm) grind	30.4	0.48	2.22	18	2.29	38.4	38.4
3/4-inch (19.05 mm) grind	28	0.53	2.48	32	2.68	39.8	39.8

- Increasing the hammer mill screen size from 1/4-inch to 3/4-inch reduced the grinding energy by more than 3 times.
- The particle dimensions changed significantly after grinding in a hammer mill fitted with different screens.

High moisture pelleting studies



Pilot scale ring die pellet mill

Pelleting data analysis

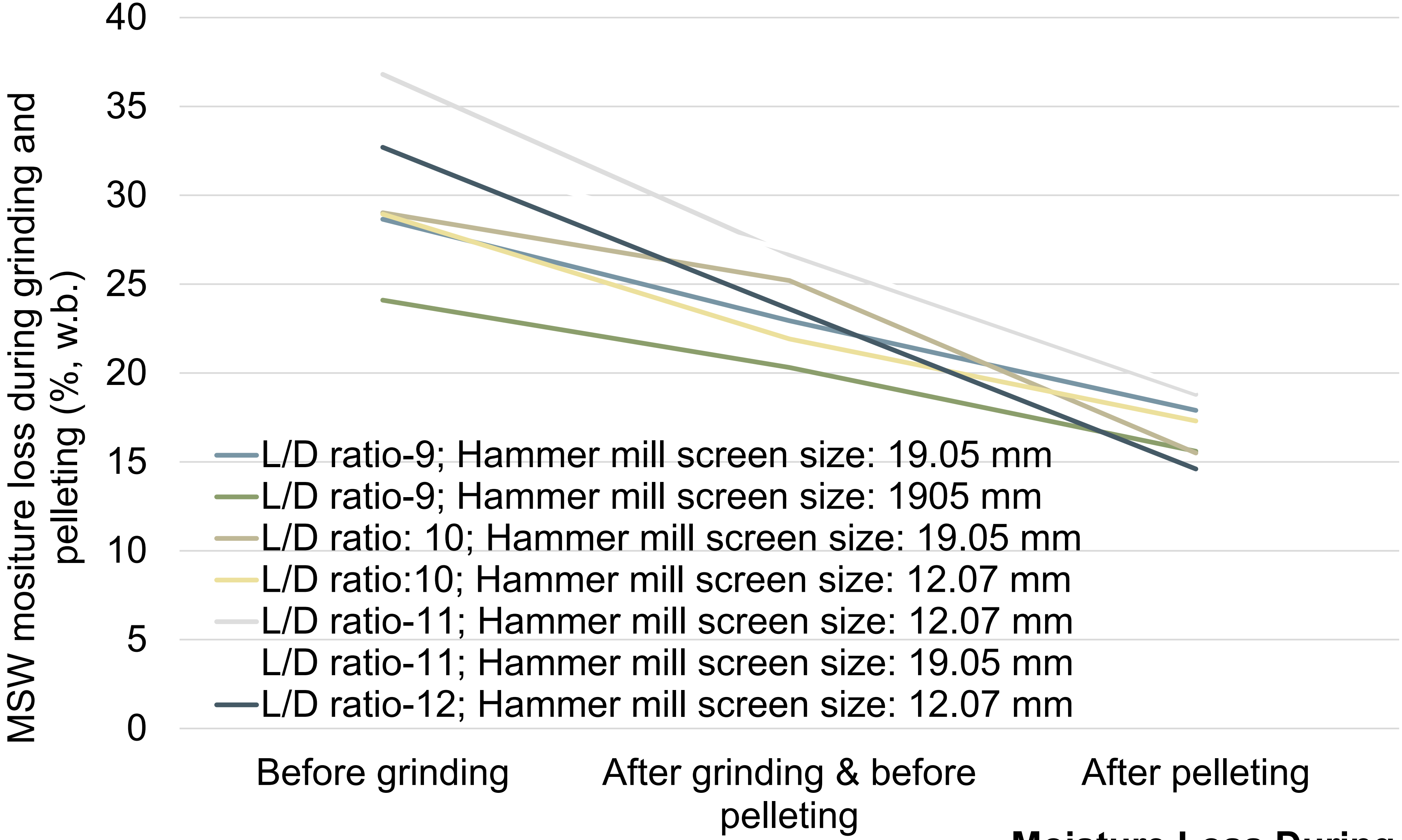
Regression models and surface plots were drawn using pelleting experimental data.

High moisture MSW grind produced after hammer milling is further used for pelleting studies

Experimental design for MSW pelleting

Hammer Mill Screen Size (mm)	L/D Ratio	Grind and Pellet Properties
12.7 (1/2-in.)	9	Pellet properties (post-pelleting) • Pellet moisture content (%, w.b.) Unit, bulk, and tapped density (kg/m^3) • Durability (%) Pellet properties (post-drying) • Unit, bulk, and tapped density (kg/m^3) • Durability (%) • Pellet moisture content (%, w.b.) • Pelleting energy consumption (kWh/ton)
12.7 (1/2-in.)	10	
12.7 (1/2-in.)	11	
12.7 (1/2-in.)	12	
19.05 (3/4-in.)	9	
19.05 (3/4-in.)	10	
19.05 (3/4-in.)	11	
19.05 (3/4-in.)	12	

High moisture pelleting studies



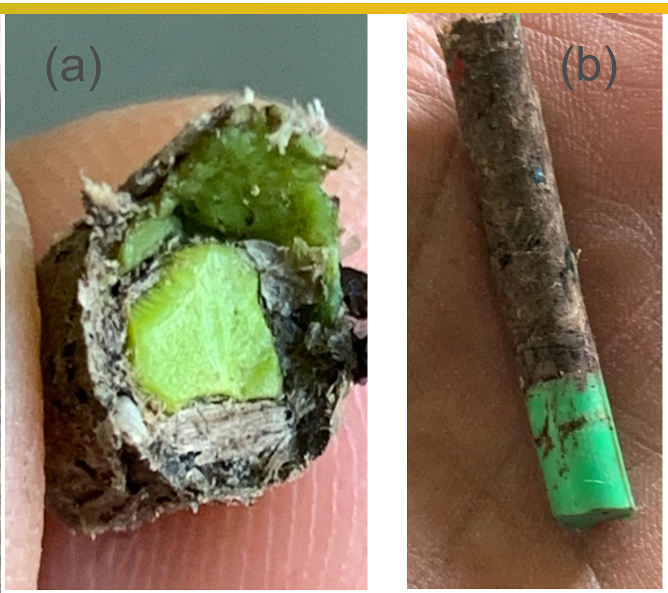
- Both grinding and pelleting impacted the moisture loss in the MSW feedstock.
- Average moisture loss was 11-13% (w.b.) during grinding and pelleting.
- A maximum moisture loss of 18% was observed during grinding and pelleting.

Moisture Loss During Grinding And Pelleting

High moisture pelleting studies

MSW pellets coming out of the pellet die.

MSW pellets made at about 25% (w.b.) moisture content using 1/2-inch hammer mill grind.



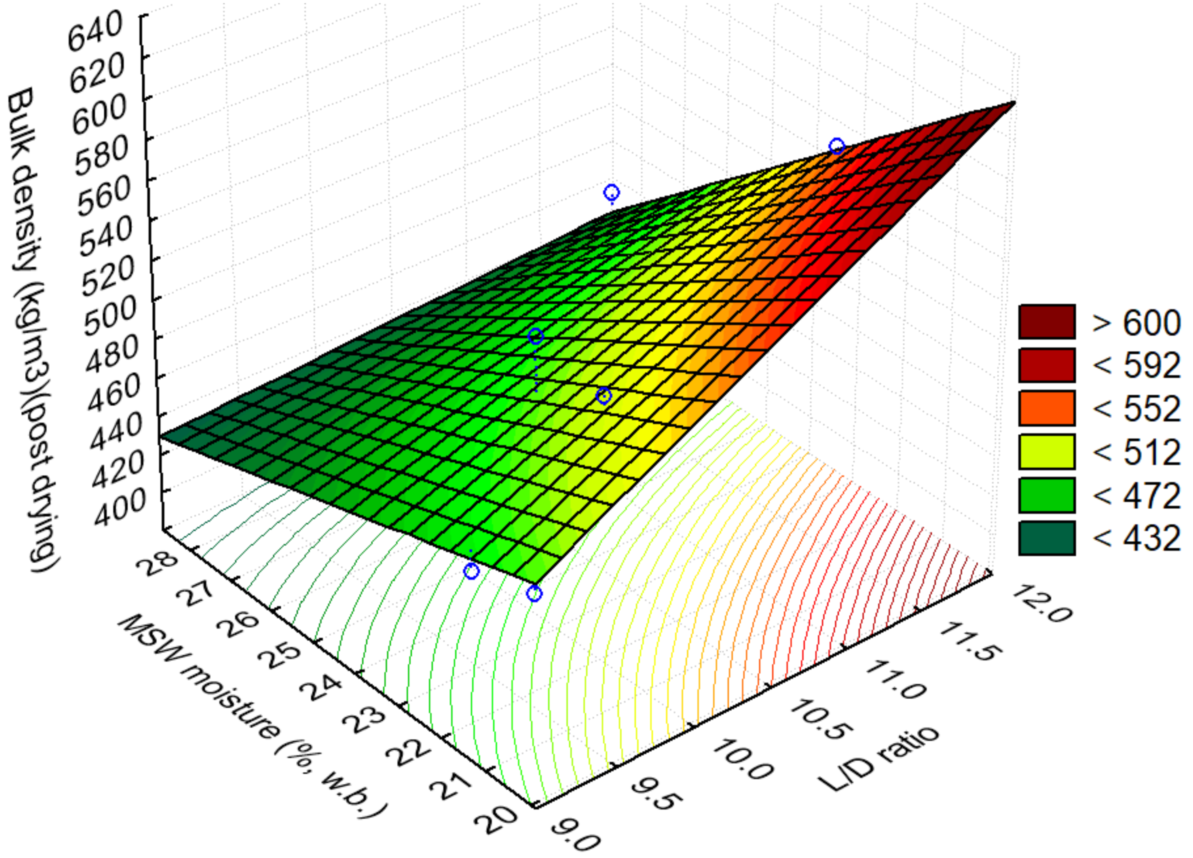
(a) Heavier plastic getting trapped inside.
(b) Lighter plastic forming a coat on the pellet.

The temperature generated during pelleting helps plastic to melt and diffuse to surface.

High moisture pelleting

MSW Pellet Bulk Density

Process conditions			Post pelleting	Post drying
Hammer mill screen size (inch)	L/D ratio	MSW grind moisture (%, w.b.)	Pellet bulk density (kg/m^3)	Pellet bulk density (kg/m^3)
19.05	9	20.31	495.28	470.63
19.05	10	24.51	544.25	492.99
19.05	11	27	502.41	430.9
12.7	9	21.28	528.43	477.03
12.7	10	23.43	560.67	523
12.7	11	24.86	492.91	480.69
12.7	12	23.55	597.78	546.74



Bulk density surface plot for 1/2-inch grind pellet

Surface plots

L/D ratio of 9 and MSW moisture of about 30% reduced the final bulk density to < 432 kg/m^3.

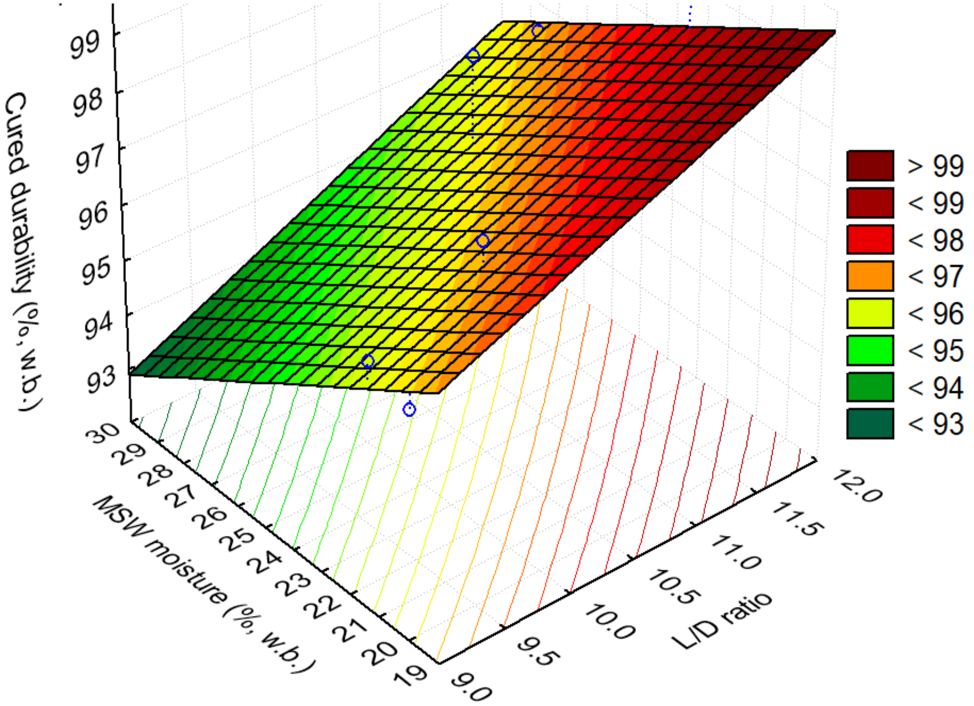
L/D ratio of 12 and MSW moisture of about 20% increased the bulk density to >600 kg/m^3.

High moisture pelleting studies

MSW Pellet Durability

Process conditions			Post pelleting	Post drying
Hammer mill screen size (mm)	L/D ratio	MSW grind moisture (%, w.b.)	Green durability (%)	Cured durability (%)
19.05	9	20.31	94.15	96.23
19.05	10	24.51	95.78	96.22
19.05	11	27	96.55	97.41
12.7	9	21.28	96.1	96.46
12.7	10	23.43	94.15	95.56
12.7	11	24.86	94.14	94.61
12.7	12	23.55	98.33	98.85

Met Go/No-Go pellet quality targets: Bulk density of about 30 lb/ft^3 (480 kg/m^3) and durability >95%



Durability surface plot for 1/2-inch grind pellet

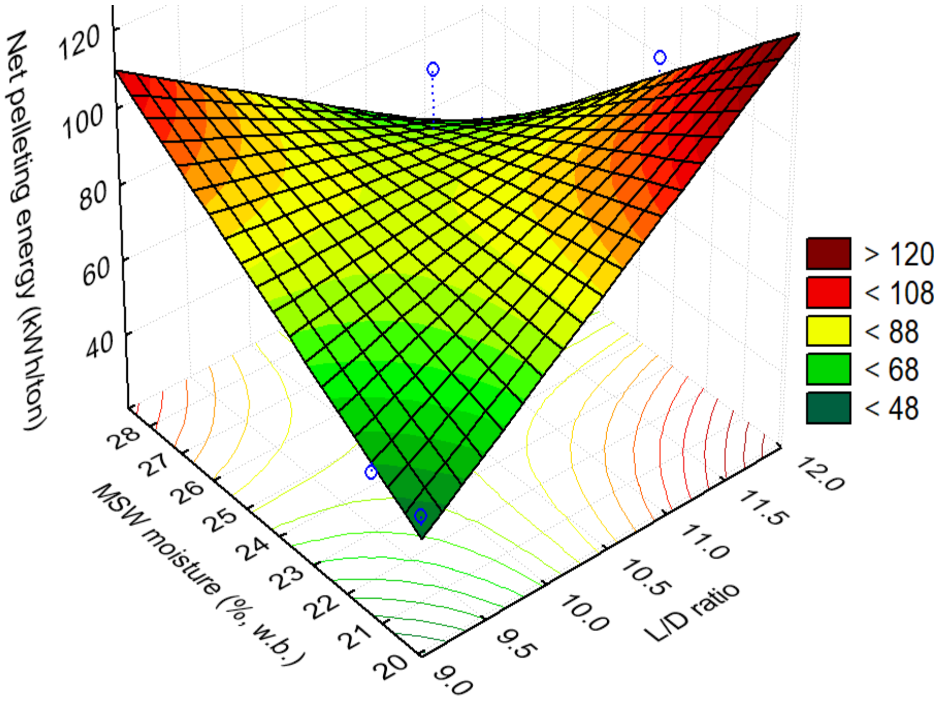
Surface plots

- L/D ratio of 12 increased the durability values >99%.
- MSW moisture of about 30% and L/D ratio of 9 lowered the durability values to <93%.

Pelleting energy consumption

MSW Pelleting energy consumption

Process conditions				
Hammer mill screen size (inch)	L/D ratio	MSW grind moisture before pelleting (%, w.b.)	Total Pelleting energy (kWh/ton)	Net pelleting energy (kWh/ton)
19.05	9	20.31	90.03	61.45
19.05	10	24.51	83.57	54.58
19.05	10	28.07	113.46	80.47
12.7	9	21.28	89.12	57.56
12.7	10	23.43	114.4	78.51
12.7	11	24.86	104.43	70.49
12.7	12	23.55	136.19	99.12



Surface plot for net pelleting energy for 1/2-inch grind MSW pellet

Surface plots

Pelleting energy consumption was influenced by both L/D ratio of the pellet die and MSW moisture content. Pelleting energy consumption increased at higher MSW moisture content and lower L/D ratio.

Samples of pellets produced in the project will be provided to Fulcrum to include in their storage bin design.

Technoeconomic analysis

MSW Pelleting Using Conventional Method Followed By The Industry (Scenario 1)

Primary Shredders (1-inch grind) (30%, w.b.) → Rotary dryer (10-12 % w.b. moisture) → Secondary shredding in hammer mill (1/4- inch screen) → Conventional pelleting → Cooler → Storage at biorefinery site

Sequence Of Preprocessing Unit Operations For High Moisture Pelleting (Scenario 2)

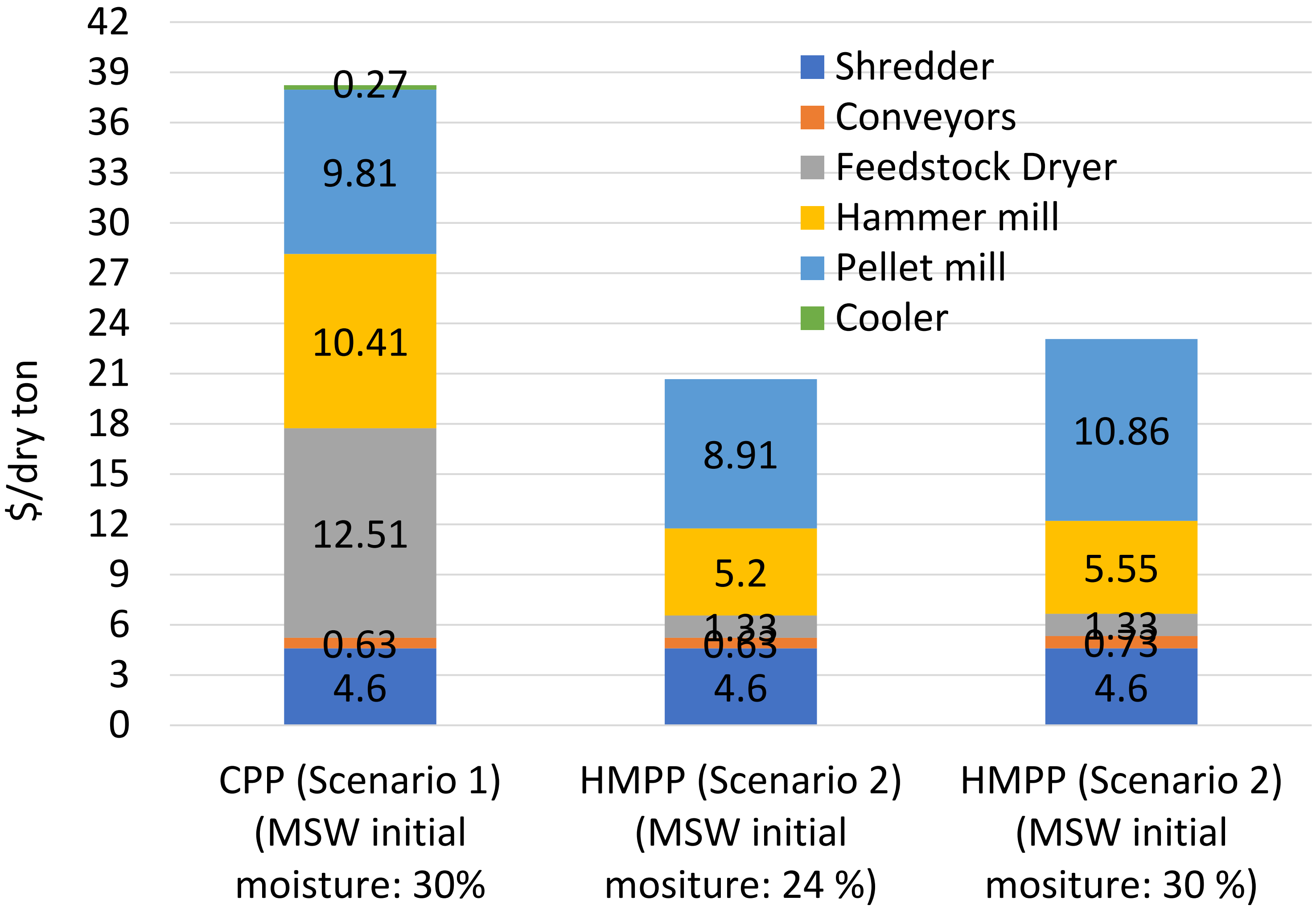
Primary Shredders (1-inch grind) (25 & 30% moisture → Secondary shredding in hammer mill (1/2- and 3/4-inch screens) → High moisture pelleting → Low temperature dryer (grain dryer) → Storage at biorefinery site

Cost calculated:

- Cost of each unit operation.
- Transportation cost.
- Greenhouse gas emissions.

- INL Biomass Logistics Model used for cost calculation
- GREET model used for greenhouse gas emissions.

Technoeconomic analysis



Conventional and high moisture pelleting cost comparison

- Rotary drying is the major energy consumer in the conventional pellet production process (about 1/3 of the total pellet production cost).

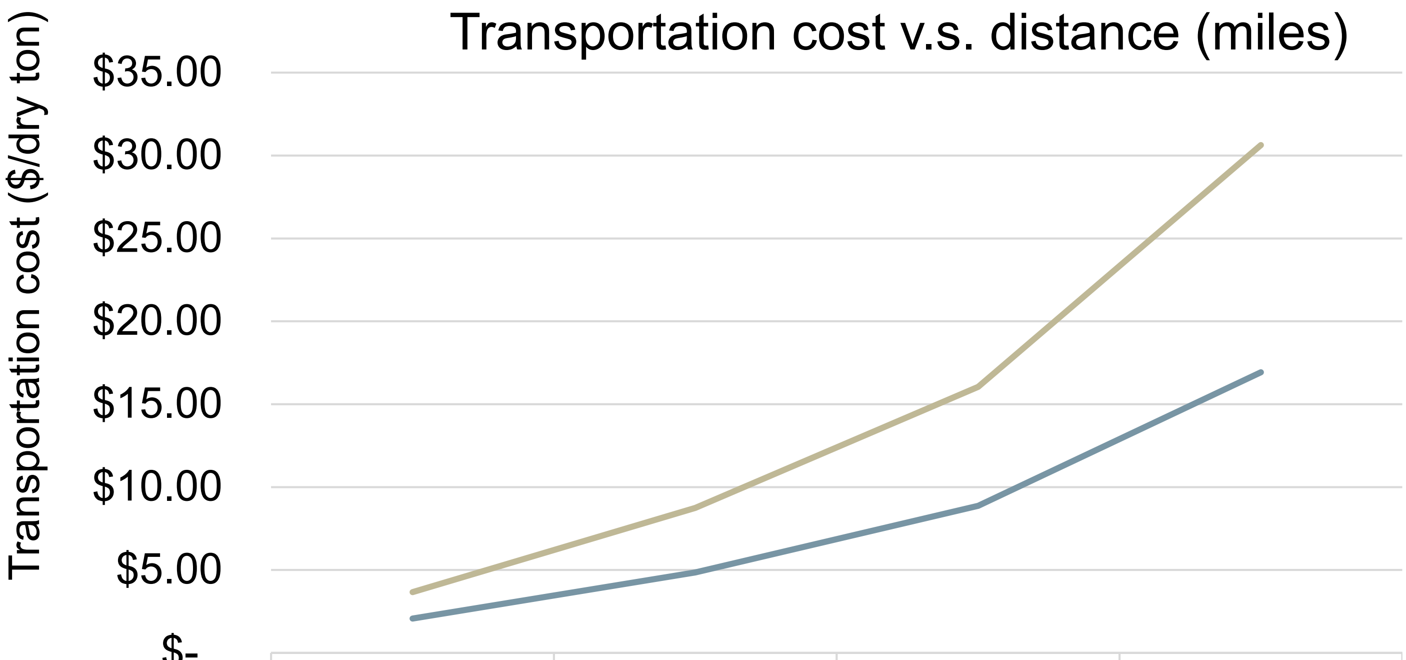
- At 24% MSW moisture HMPP is 46.12% lower cost than conventional pelleting
- At 30% MSW moisture HMPP is 39.82% lower cost than conventional pelleting

We expect more cost savings when fractional milling is tested in this year

- The other benefits of using pellets in terms of storage, transportation, feeding, handling and conversion performance improvements need to be quantified in term of $/ton

Note: HMPP: High moisture pelleting process

Transportation cost



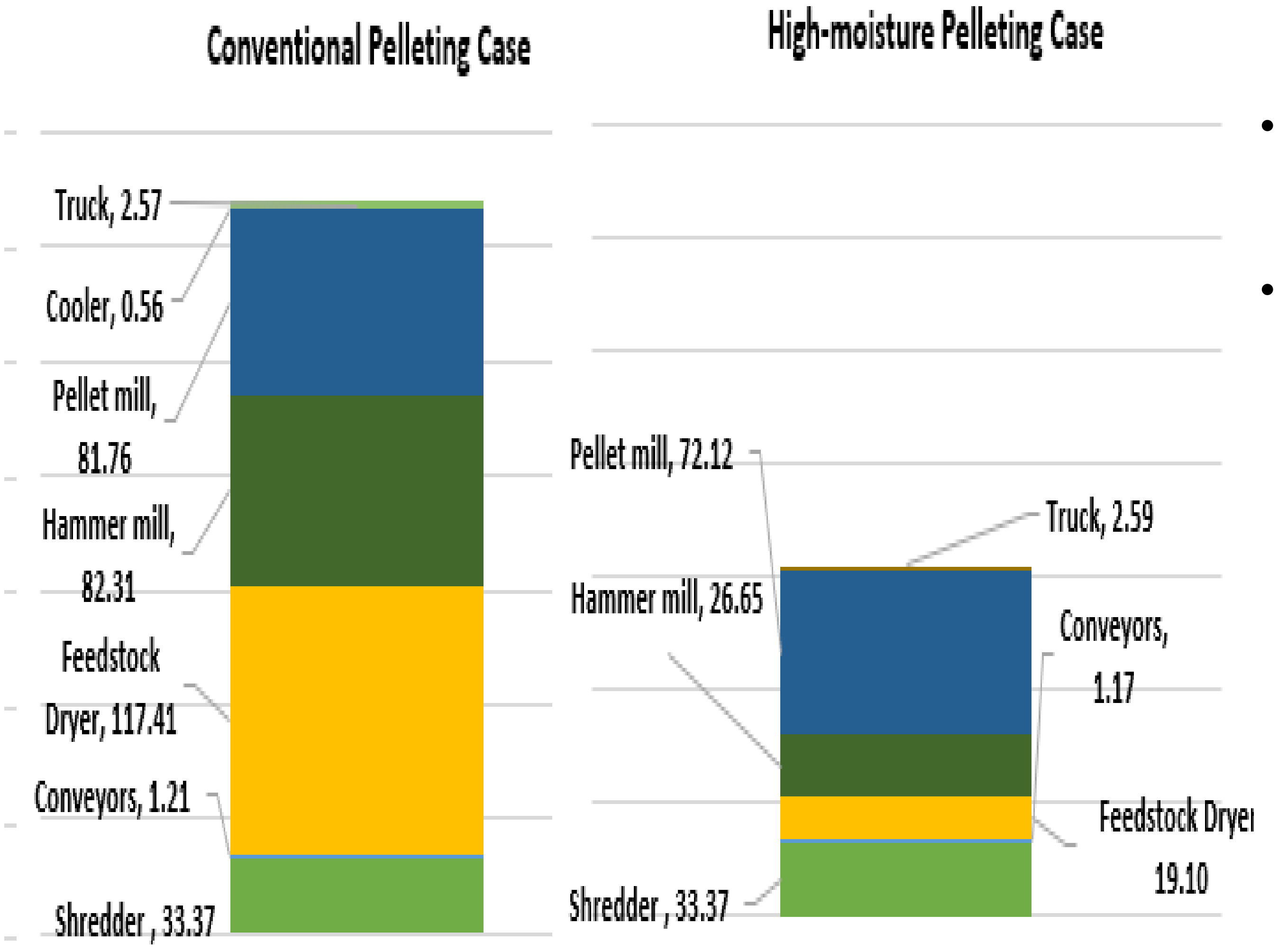
	15	50	100	200
Pelleted MSW (10% w.b., 500 kg/m3)	$2.07	$4.85	$8.87	$16.93
Compacted MSW (30% w.b., 150 kg/m3)	$3.66	$8.74	$16.05	$30.63

Final bulk density of MSW has a significant impact on transportation cost.

For transportation distances of more than 50 miles pelleting helps to reduce the transportation cost by about 50%.

Transportation Cost for Compacted MSW, and Pelleted MSW for different transportation scenarios

Greenhouse gas emissions



- For conventional pelleting of MSW at 30% moisture the total GHG emissions are about 285.81 kg CO_2 equivalent/dry ton.
- For high moisture pelleting of MSW at 30% initial moisture, GHG emissions are 155.00 kg CO_2 equivalent/dry ton.

Using bigger screen size in stage-2 grinder and low temperature dryer for drying pellets has a significant impact on GHG emissions.

The CO_2 emission is about 46% lower for high moisture pelleting compared to conventional pelleting.

GHG emission comparison of conventional pelleting and high moisture pelleting

Summary

Management:

(1) DOE Merit Review in 2019. (2) Biweekly call with Fulcrum to discuss the project progress. (3) Project milestones achieved. (4) Major milestones with definite quality and cost targets. (5) Go/No-Go milestone. (6) Work with INL analysis team to update the state of technology costs based on the results obtained in this project. (7) FCIC quarterly and annual meeting updates. (8) DOE peer review.

Technical Approach:

Advanced preprocessing technologies such as fractional milling, high moisture pelleting, and low temperature drying developed by INL will be used to meet the cost and quality targets established in the project.

Impact: This project will enable INL and FCIC to understand how the properties of MSW-derived feedstock impact: (i) moisture reduction; (ii) quality of densified products; and (iii) energy consumption of the preprocessing systems developed by INL.

Progress:

This task has delivered all the major milestones, go-no-go milestone and technical achievement to date.

Future work:

- Completing high-moisture pelleting tests on commercial scale pellet mill.
- Fractional milling studies on MSW.
- Integrated demonstration of advanced preprocessing technologies.
- TEA based on the integrated demonstration data.

Quad Chart Overview

Timeline

- 10/01/2019 – 09/30/2021

	FY20 Costed	Total Award
DOE Funding	$206,943	$1,018,000
Project Cost Share	$25,053.54	$440,000

Project Partners*

- Fulcrum Bioenergy Inc.

Project Goal

The objective of this project is to efficiently manage the material properties and improve the handleability of MSW-derived feedstock using the fractional milling, high moisture pelleting, and low temperature drying preprocessing technologies developed by INL.

The goal of the project is to produce a densified product with a bulk density of about 480kg/m^3, durability of >95% and moisture content <10% (w.b.) at a 40% reduced preprocessing cost compared to current baseline cost (the base line cost for preprocessing MSW will be established in the project).

End of Project Milestone

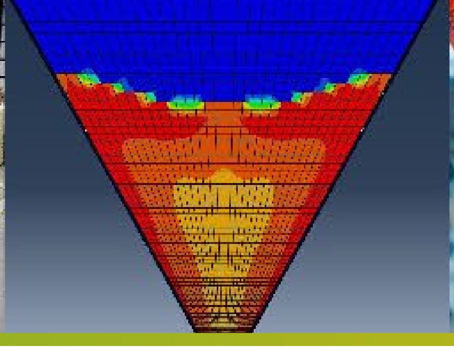
Integrated demonstration of fractional milling, high moisture pelleting and low temperature drying to lower municipal solid waste moisture content to ≤ 10% (w.b.) from an initial moisture content of 30% (w.b.) and achieve feedstock cost and quality targets. Develop a cost estimate for installation of INL fractional milling, high moisture pelleting and low-temperature drying process to meet Fulcrum's commercial processing requirements.

Funding Mechanism

FCIC-DFO

*Only fill out if applicable.



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