DOE Bioenergy Technologies Office (BETO) 2021 Project Peer Review

Characterization of Mechanical Biomass Particle-Particle and Particle-Wall Interactions

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Feedstock Technology Program

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Project Overview

- *Aims to contributing to understanding roles of 'biomass physical and chemical characteristics to feedstock performance in handling and conversion operations.'*
- Early-stage research on variability in friction and adhesion of biomass particles relative to tissue type
- *Determining friction and adhesion properties, and their variabilities of southern pine residue and corn stover particles from different anatomical origins at particle scale*

1. Management; Project Team

Penn State

- Characterization and modeling of biological and particulate materials
  - Physical and Mechanical Properties of Ag. and Bio. Materials
  - Powder Mechanics; Storage, Conveying, Flow, Segregation, and Compaction
- Personnel
  - Project Director: Dr. Hojae Yi, PhD
  - Yiming Li, (PhD Student)
  - James Slosson (MS Student)
- Developing micro-mechanical devices and conducting experiments

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- Biomass technology company
  - Toll-processing plant
  - Design, build, sell feedstock preprocessing equipment
  - Strong relationships with labs and universities
- Personnel
  - Project Director: Dr. Jim Dooley, PhD, PE
  - Project Lead: Chris Lanning, PE
- Feedstock collection, fractionation, and size reduction (milling)

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1. Management; Risk mitigation

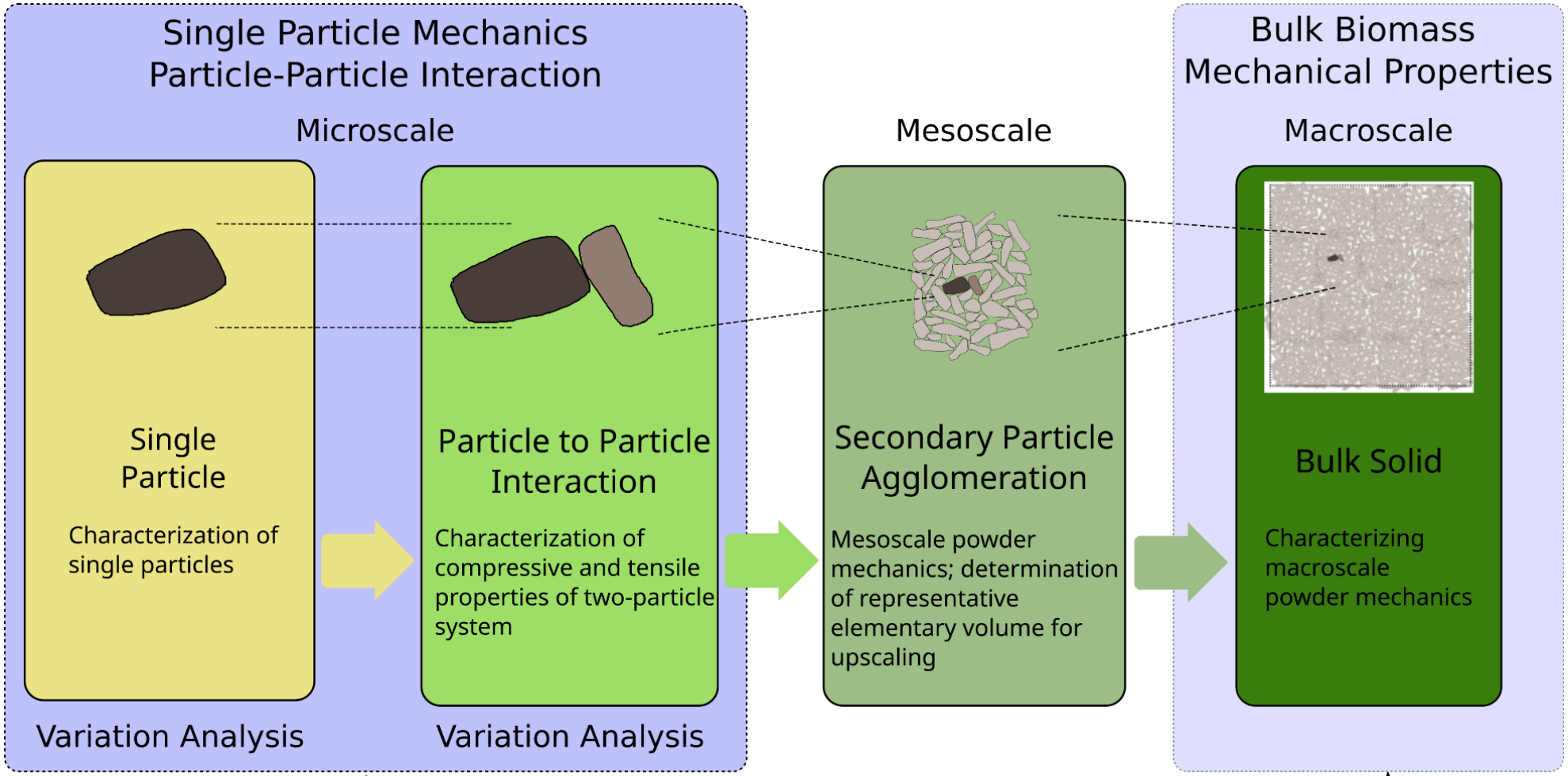
- Management Plan
  - Minimizing risks by employing respective expertise and regular communications (Monthly via Zoom and MS Teams)
  - Project Progress Management: Quarterly progress update meeting and reports with project officer and monitor
  - Go/No-Go Decision Meeting to ensure meeting the proposed deliverables
- Critical Success Criteria
  - Test device design and protocol for biomass particle interactions
  - Data set of corn stover and southern pine residue interparticle and particle-wall interactions (friction and adhesion)

1. Management; Objectives

Objectives (Tasks)	Budget Period / Year
1. Verification	BP1; 2020
2. Procure southern pine residue and corn stover, fractionate, and mill	BP2; 2021
3. Design, build, and commission of a Micro-Mechanical Extensometer (MME)	BP2; 2021-2022
4. Develop a force-displacement analysis protocol	BP2; 2021-2022
5 and 6. Measure the friction and adhesion of particle-particle and particle-wall	BP3; 2022-2023
7. Variability analysis of measurements and correlation analysis with the bulk biomass flow properties	BP3; 2023

2 – Approach; Background

- Multi-scale nature of bulk biomass behavior



2 – Approach; Materials and Fractions

Southern Pine Forest Residues Material	Corn Stover
Commingled ground/chipped residues	Commingled processed from bales
Clean wood chips	Stems with nodes and pith
Needles	Leaves
Bark	Husks
Milled twigs and small branches with bark	Cobs
Composite blended sample	Composite blended sample

Raw pine biomass anatomical fractions

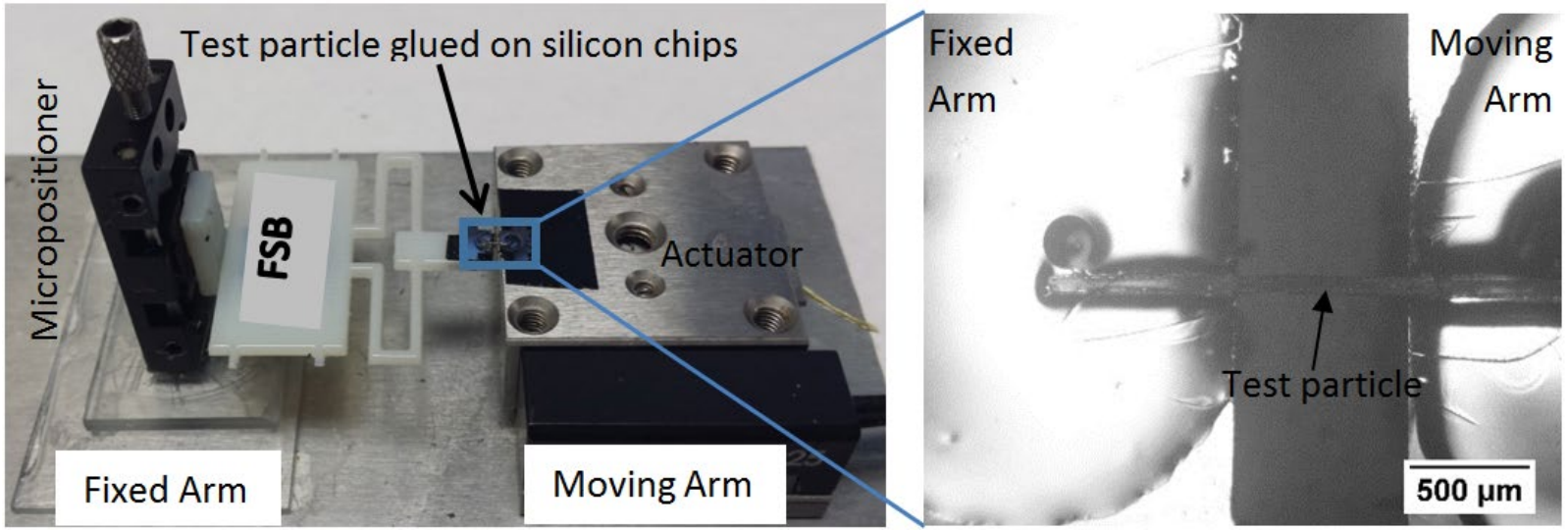
Reactor-ready milled pine fractions

Raw corn stover biomass anatomical fractions

Reactor-ready milled corn stover fractions

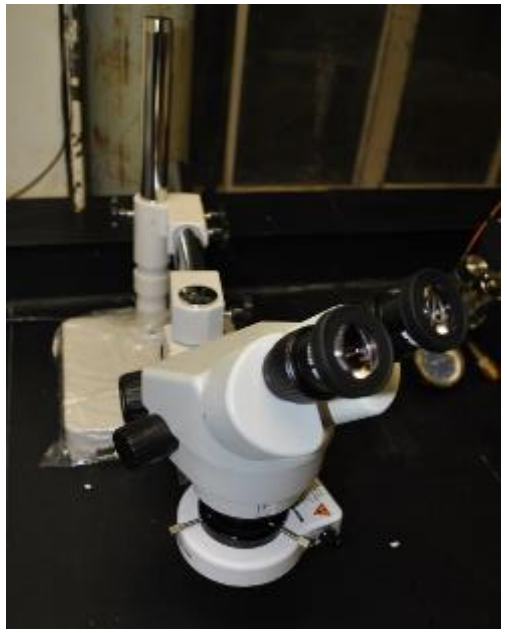
2 – Approach; Micro-Mechanical Extensometer

- Successfully used for characterizing mechanical properties of plant and biological samples of sub-millimeter size (Zamil et al., 2013, 2014, 2015; Kim et al., 2015)
- Needs modifying micro-extensometer for milled southern pine residue and corn stover particles from different anatomical origins



2 – Approach; MME Result Analysis Protocol

- MME will be designed to have a range and resolution for 2 mm southern pine residue and corn stover particles from different anatomical origins
- Each test specimen will be mounted on an MME tester under a dissection microscope
- MME test will be conducted under a microscope and results will be stored as sequential digital images

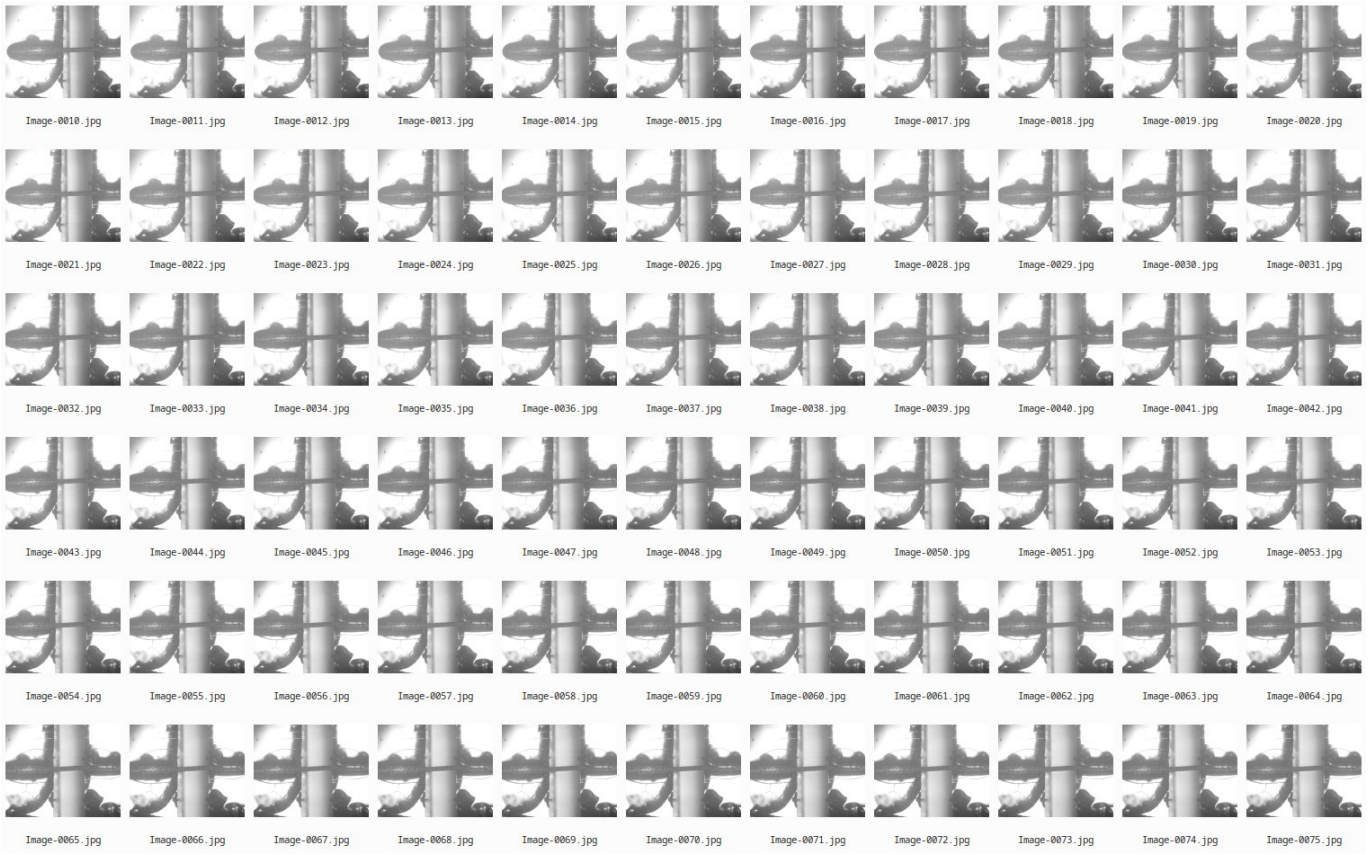


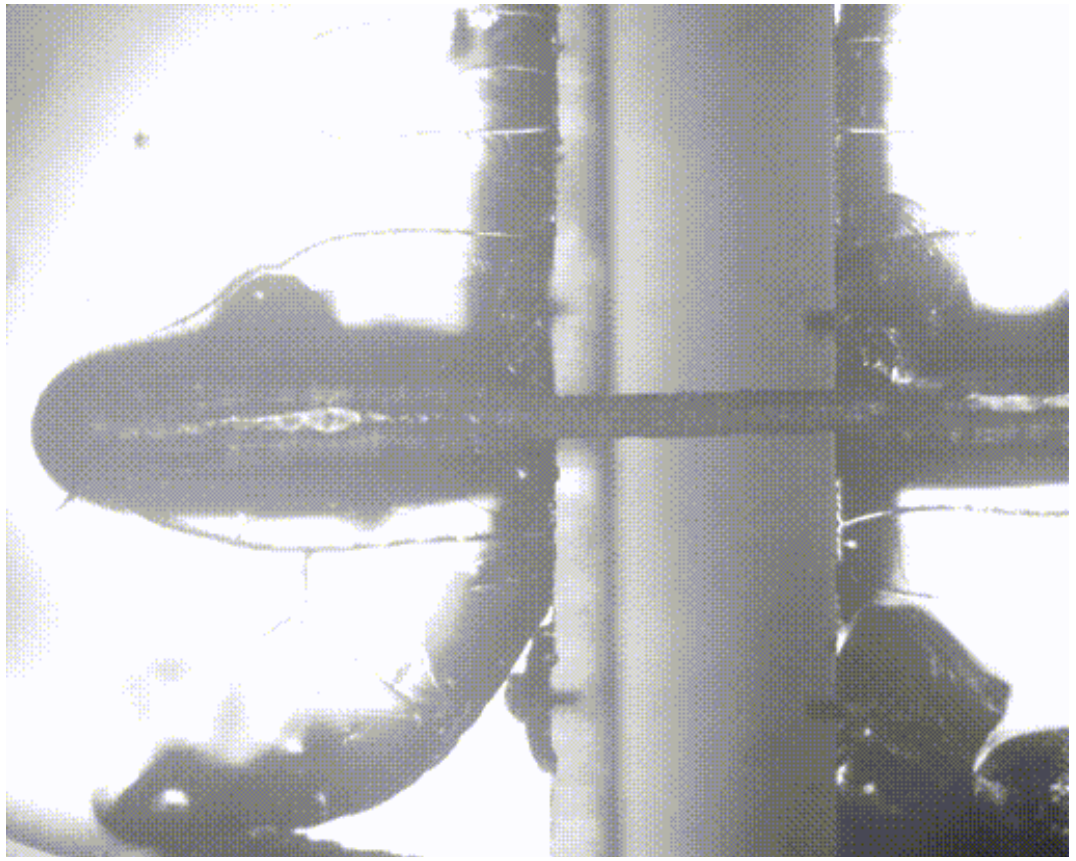
Dissection Microscope

Bright-field Microscope with Digital Image Capturing Device

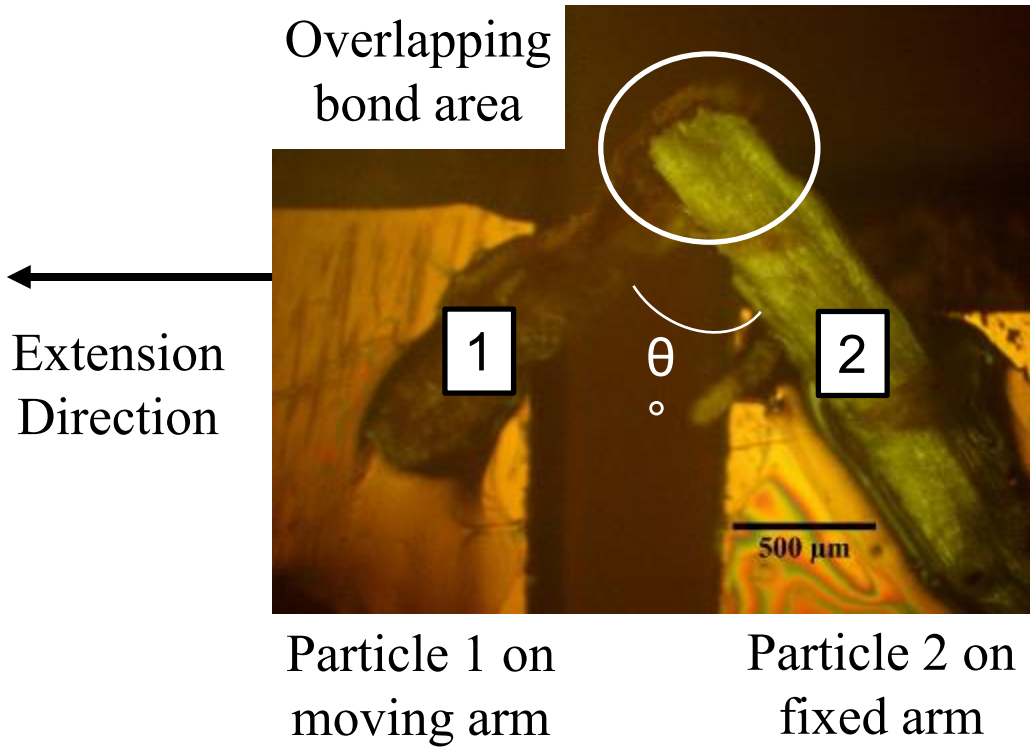
2 – Approach; Typical MME Test Results

- Tensile test of milled switchgrass particle from no-load to failure





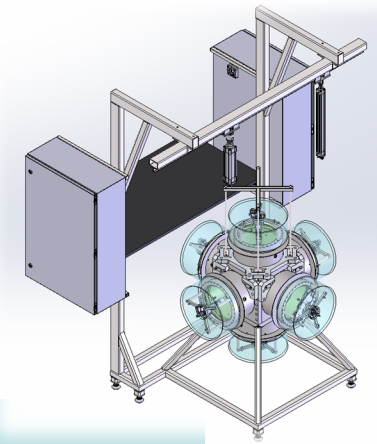
2 – Approach; Inter-Particle Friction and Cohesion



- In previous study, particle-particle interaction (bond strength) was successfully determined (Karamchandani et al. 2019. KONA Powder and Particle Journal 36: 252–63.)
- We will adopt the micro-extensometer for inter-particle friction and adhesion tests
- Appropriately force sensor beam is the key to achieving required resolution of the micro-extensometer
- RISK: Accurate measurement of the contact area – utilize profilometer or other surface characterization tools

2 – Approach; Variability and Correlation Analysis

- Variability analysis (R or Python + pandas) for biomass particle-particle friction and adhesion
- Correlation analysis between interparticle properties and bulk biomass properties



MME Test Results	Bulk Biomass Properties
• Stiffness of individual particle • Friction and cohesion between biomass particles • Friction and cohesion between biomass particle and wall	• Failure stress of bulk biomass • Angle of internal friction and Cohesion coefficient of Mohr-Coulomb model • ϕ and d of Drucker-Prager model • M and β of modified Cam-Clay model

- This study will improve understanding and reliability of biomass material handling

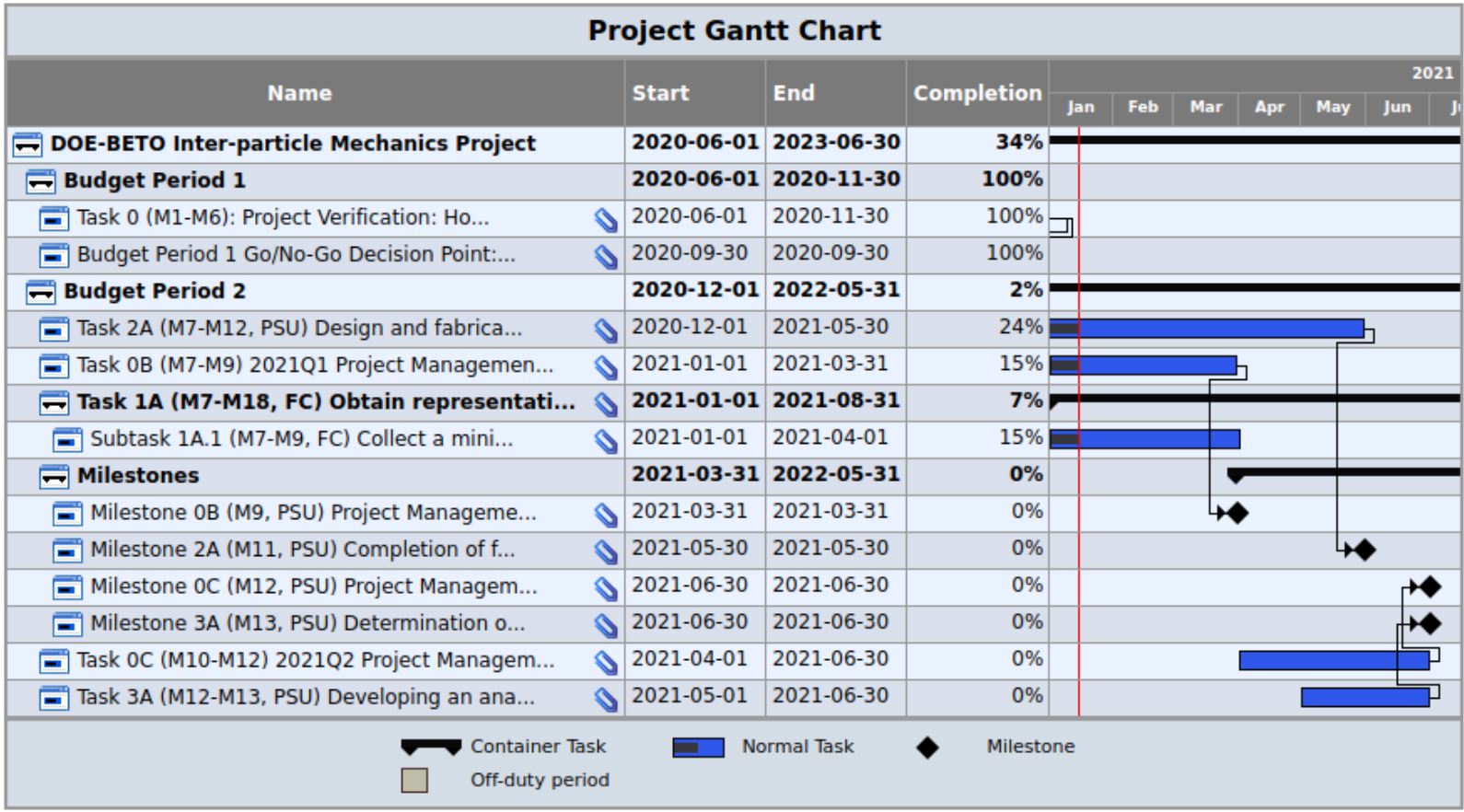
- Karamchandani, A, H. Yi, and V. M. Puri. 2016. “Comparison and Explanation of Predictive Capability of Pellet Quality Metrics Based on Fundamental Mechanical Properties of Ground Willow and Switchgrass.” Advanced Powder Technology 27 (4): 1411–17.
- —. 2018. “Comparison of Mechanical Properties of Ground Corn Stover, Switchgrass, and Willow and Their Pellet Qualities.” Particulate Science and Technology 36 (4): 447–56.
- —. 2019. “Micromechanical Characterization of Particle-Particle Bond in Biomass Assemblies Formed at Different Applied Pressure and Temperature.” KONA Powder and Particle Journal 36: 252–63.

3 – Impact

- Contributing to the understanding of key particle level characteristics of southern pine and corn stover particles of anatomical fractions and their variabilities to enable engineering of biomass supply systems to handle, store, and deliver conversion-ready feedstocks reliably
- Addressing technical barriers in ‘Biomass Material Handling and Transportation’ and ‘Operational Reliability of Integrated Biorefinery’
- Expected contribution of this project includes
  - Novel quantitative data for biomass particle level modeling approaches (e.g., Discrete Element Modeling)
  - Novel knowledge of values and variabilities in the friction and adhesion between 1) biomass particles and 2) biomass particles and a wall material
  - Mechanical test device and protocol capable of characterizing the behavior of millimeter-scale plastic samples of plant-origin at the particle level
  - Variability analysis result will inform biomass handling strategy: Need for screening, debarking, lumped collection, etc.

4 – Progress and Outcomes

- Go decision of BP1 with a successful verification completion (November 2020)
- BP2 with actual technical tasks are just starting
- No roadblocks or delays
- Upcoming Tasks & Milestones
  - 1A Obtain biomass samples
  - 2A Design and fabrication of MME for biomass particle experiments
  - 3A Determination of mechanical properties of biomass particles from commingled southern pine residues and corn stover



Summary

- *This project aims to gain insights on how biomass physical and chemical characteristics at particle level are correlated to feedstock handling performance*
- *This project plans to determining friction and adhesion properties, and their variabilities of southern pine residue and corn stover particles from different anatomical origins*
  - *Obtain fractionated southern pine residue and corn stover per anatomical origin*
  - *Develop micro-mechanical extensometer suitable for characterizing biomass particle samples*
  - *Determine inter-particle and particle-wall mechanical properties*
  - *Analyze the variability of determined interparticle properties and the correlation to the bulk mechanical properties pertinent to the biomass handling*
- *We expect that the successful completion of this project will have broad impacts in improving biomass handling by engineering biomass preprocesses with necessary data of biomass particles for advanced modeling approaches, e.g., discrete element modeling or analytical biomass flow models*

Quad Chart Overview

Timeline

- 10/01/2019
- 03/31/2023

	FY20 Costed	Total Award
DOE Funding	(10/01/2019 – 9/30/2020) $5,181	$707,323
Project Cost Share	$1,295	$200,335

Project Partners*

- Forest Concepts

Project Goal

The goal of the proposed project is to contribute to the understanding of key characteristics of southern pine and corn stover anatomical fractions and their variabilities to enable engineering of biomass supply systems to handle, store, and deliver conversion-ready feedstocks reliably.

End of Project Milestone

- Micro-Mechanical Extensometer and particle scale test protocol
- Variability of friction and adhesion of corn stover and southern pine residue particles
- Variability of friction and adhesion of biomass particles and a wall material

Funding Mechanism

DE-FOA-0002029 DOE BETO 2019 Multi-topic FOA

Topic Area 2a: Relating Biomass Physical and Chemical Characteristics to Feedstock Performance in Handling and Conversion Operations