U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Biomass Feedstock Supply Challenges and Solutions with Idaho National Laboratory

Presenters:

Dr. Lynn Wendt, Bioenergy Program Lead, Idaho National Laboratory

Dr. Luke Williams, Research Scientist, Idaho National Laboratory

January 20, 2022

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- U.S. Department of Energy (DOE) Bioenergy Technologies Office (BETO)

BETO & DOE National Laboratory Members:

- Bioenergy communicators, laboratory relationship managers, BETO tech team, and education and workforce development professionals

Purpose:

- Communications strategy for BETO-funded bioenergy research and development

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Today's Agenda

I. Dr. Lynn Wendt presenting on Feedstock Logistics and Preprocessing Research and Development at Idaho National Laboratory (INL)

II. Dr. Luke Williams presenting on the Challenges and Solutions for Working with Wastes at the Biomass Feedstock National User Facility (BFNUF)

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Today's Presenters

Dr. Lynn Wendt
Bioenergy Program Lead
Idaho National Laboratory

Dr. Luke Williams
Research Scientist
Idaho National Laboratory

Feedstock Logistics and Preprocessing R&D at INL

Lynn M. Wendt, Ph.D.
Bioenergy Program Lead
Idaho National Laboratory

January 20, 2022

Idaho National Laboratory

INL's Biomass Feedstock National User Facility

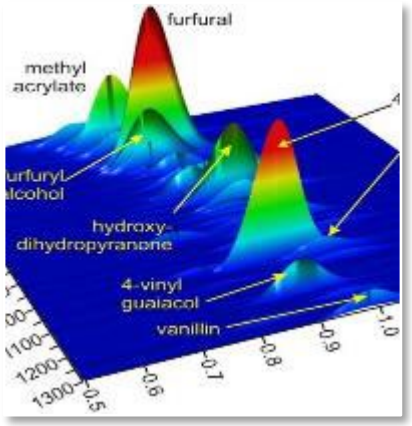
Feedstock logistics, preprocessing, and modeling capabilities spanning bioenergy supply chain

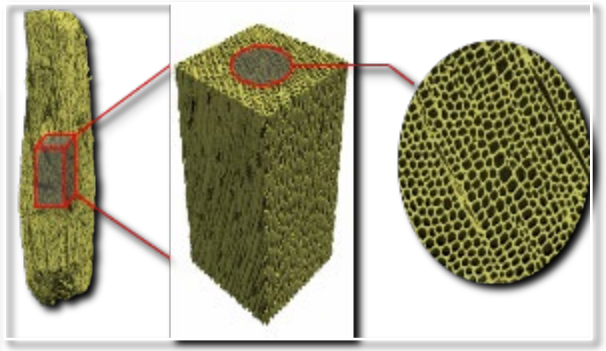
Feedstock Supply & Logistics
- Resource mobilization
- Cost and energy analysis

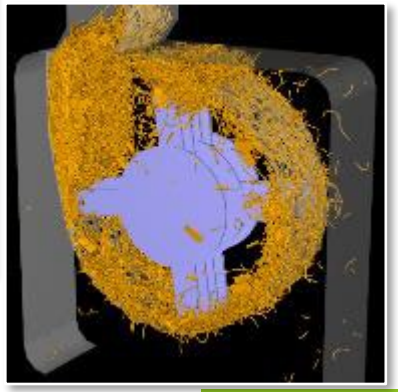
Biomass and MSW Variability Management
- Feedstock characterization

Mechanical Preprocessing R&D
- Artificial intelligence-based materials preprocessing

Scale-up for Conversion-Ready Feedstocks
- Testing, development, and scale-up







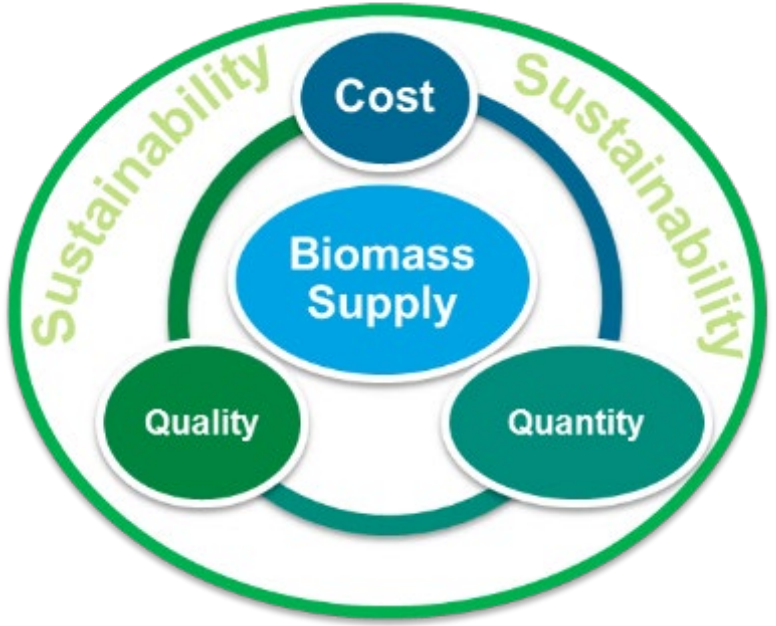
Feedstock Supply Chain Challenges

Feedstock Supply and Logistics | *Preprocessing* | *Conversion*

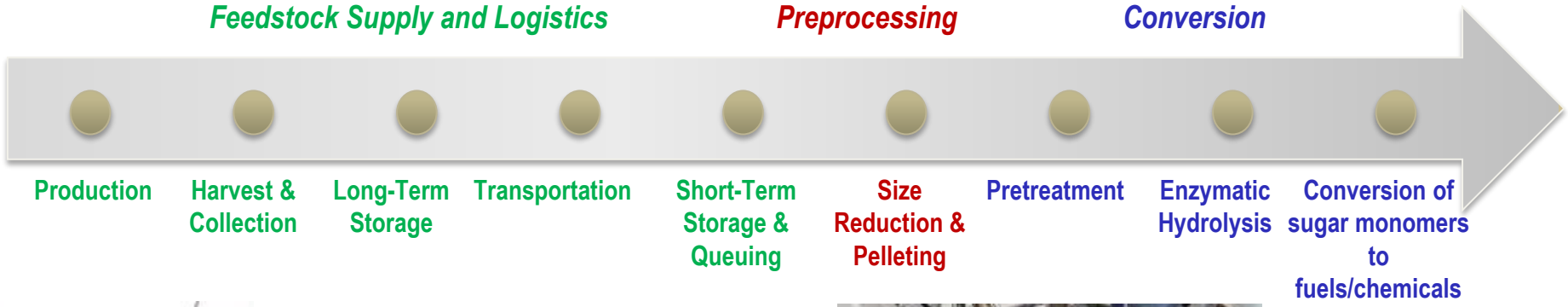
Production | Harvest & Collection | Long-Term Storage | Transportation | Short-Term Storage & Queuing | Size Reduction & Pelleting | Pretreatment | Enzymatic Hydrolysis | Conversion of sugar monomers to fuels/chemicals

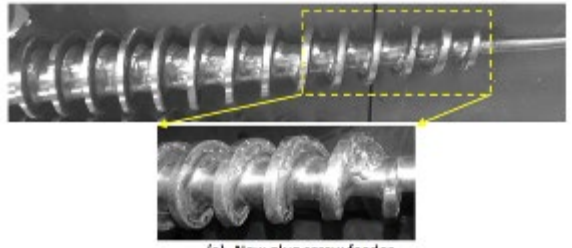
What are biorefineries up against?

- Flowability, feeding, and handling
- Feedstock variability
- Equipment uptime/downtime

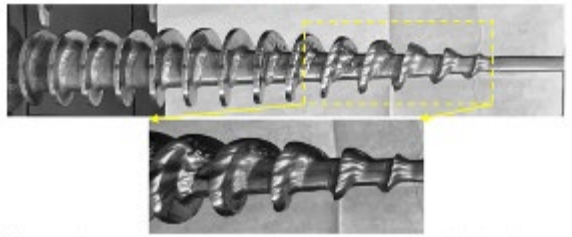


Feedstock Supply Chain Challenges



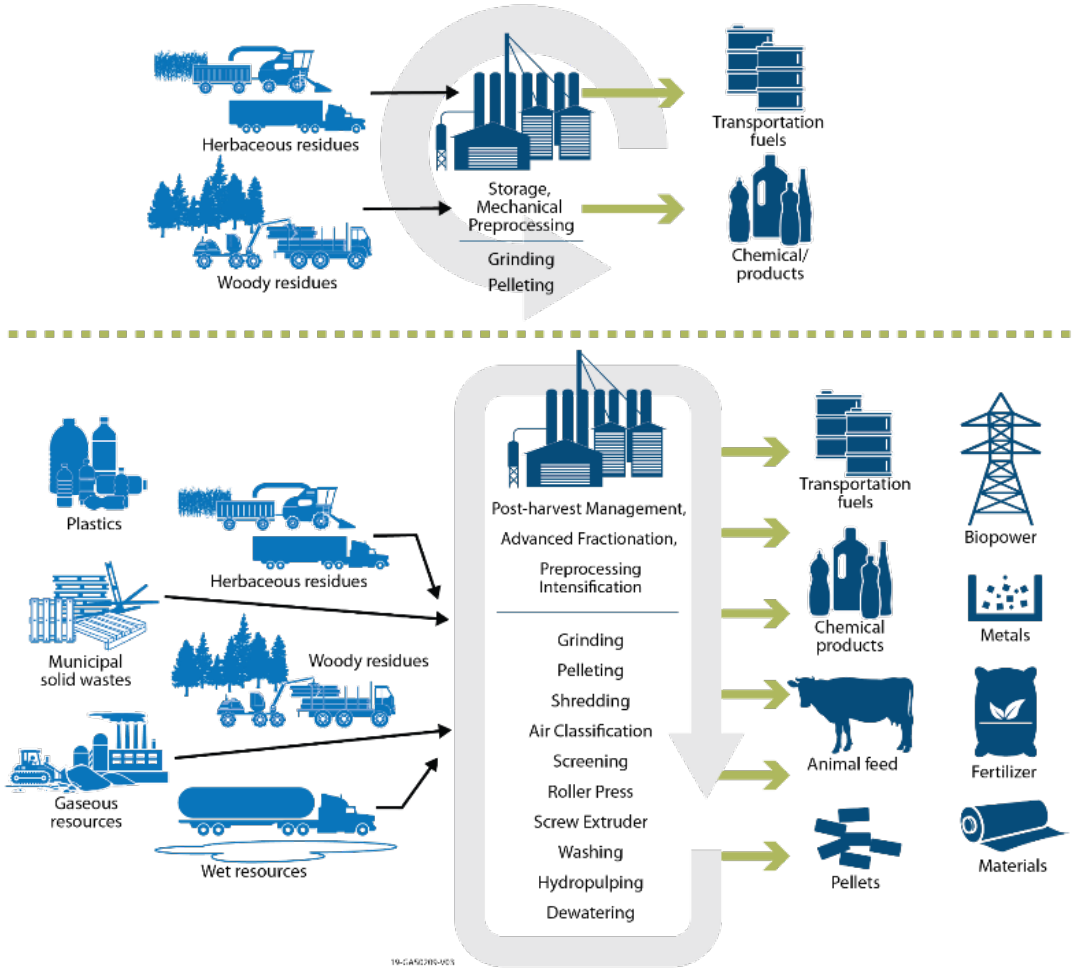


(a) New plug screw feeder



(b) Worn plug screw feeder after merely 54 hrs of operation with high-ash corn stover

Quality-by-Design Feedstock Supply Chain



Uniform Format Feedstock Supply System

Simple supply systems that grinds, dries, and densifies

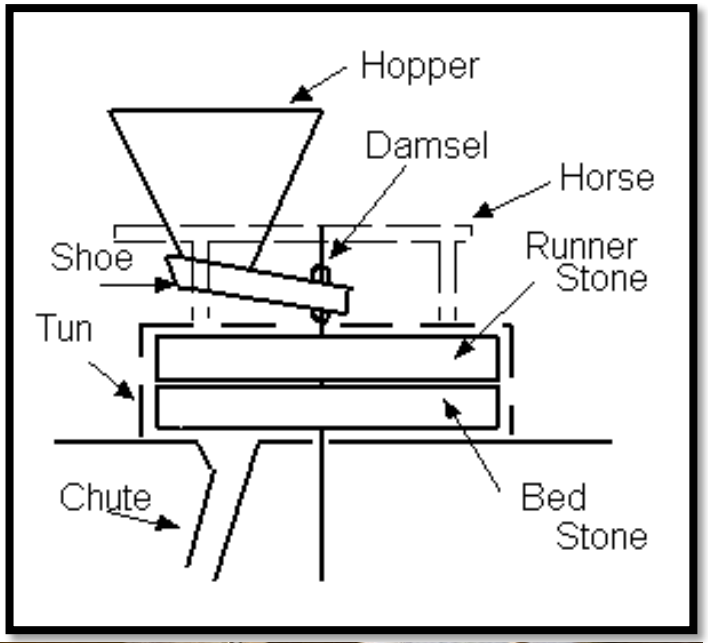
Quality-by-Design Feedstock Supply System

Expands preprocessing operations:

- Enables access to new feedstocks
- Selective pairing of feedstock fractions and conversion processes
- Fractionation, merchandising, and value-add are key

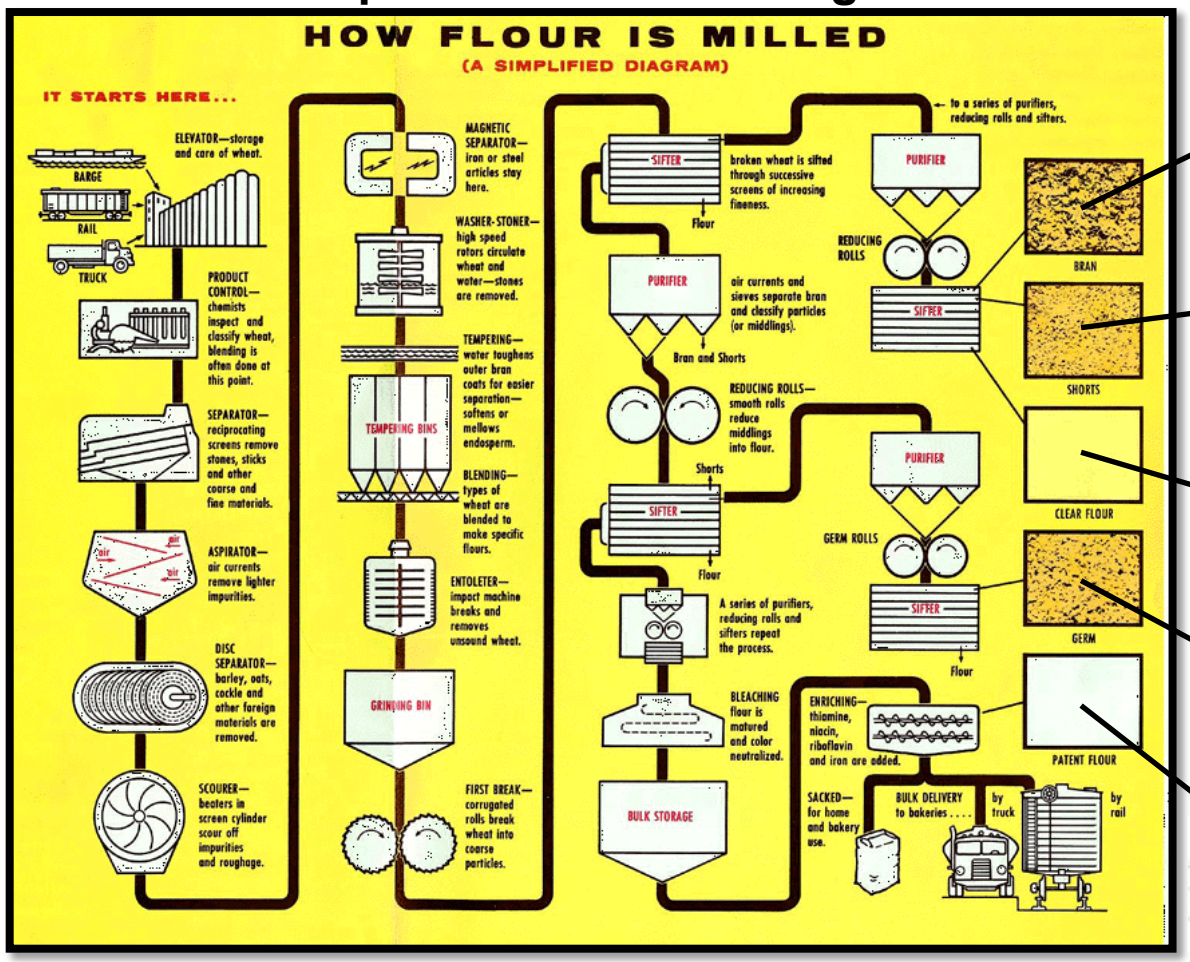
Accelerating the Process of Innovation

Grist Mill Diagram



Whole Wheat Stone Milled Flour

Simplified Roller Mill Diagram



Bran

Shorts

Clear Flour

Germ

Patent Flour

Quality Is an Issue for all Biomass Resources

Forest Residues

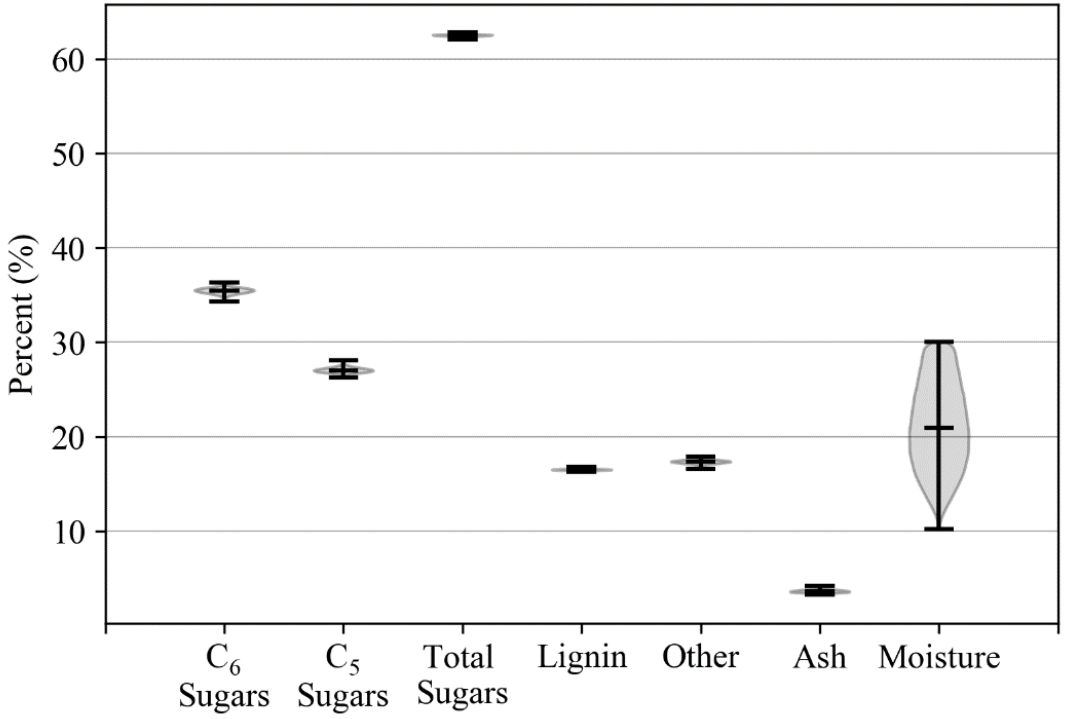
Corn Stover Bales

Municipal Solid Waste

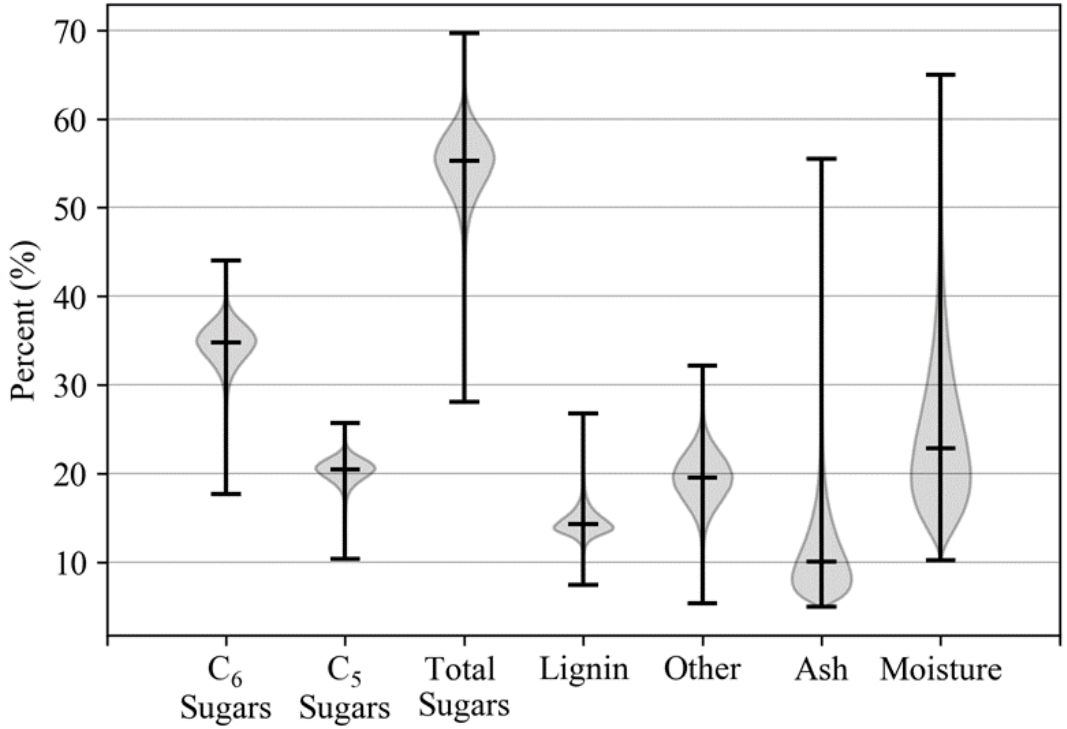
- Raw biomass DOES NOT meet feedstock specifications
- Diversity and variability requires preprocessing of raw biomass to achieve feedstock specification

Raw Biomass Meets Less than 30% of Biorefinery Specifications

Biorefinery Feedstock Quality Specs

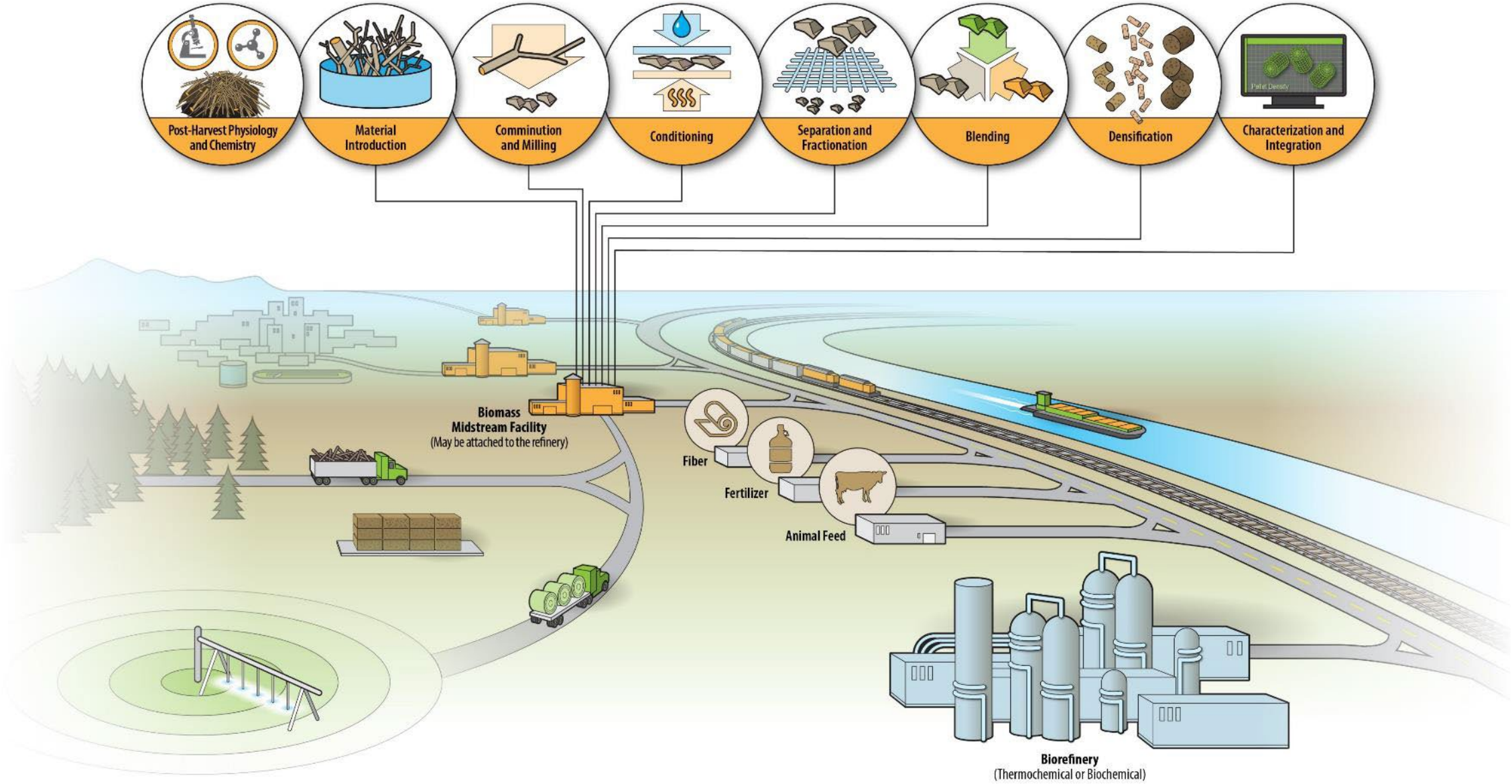


Field-Run Stover Quality Variability



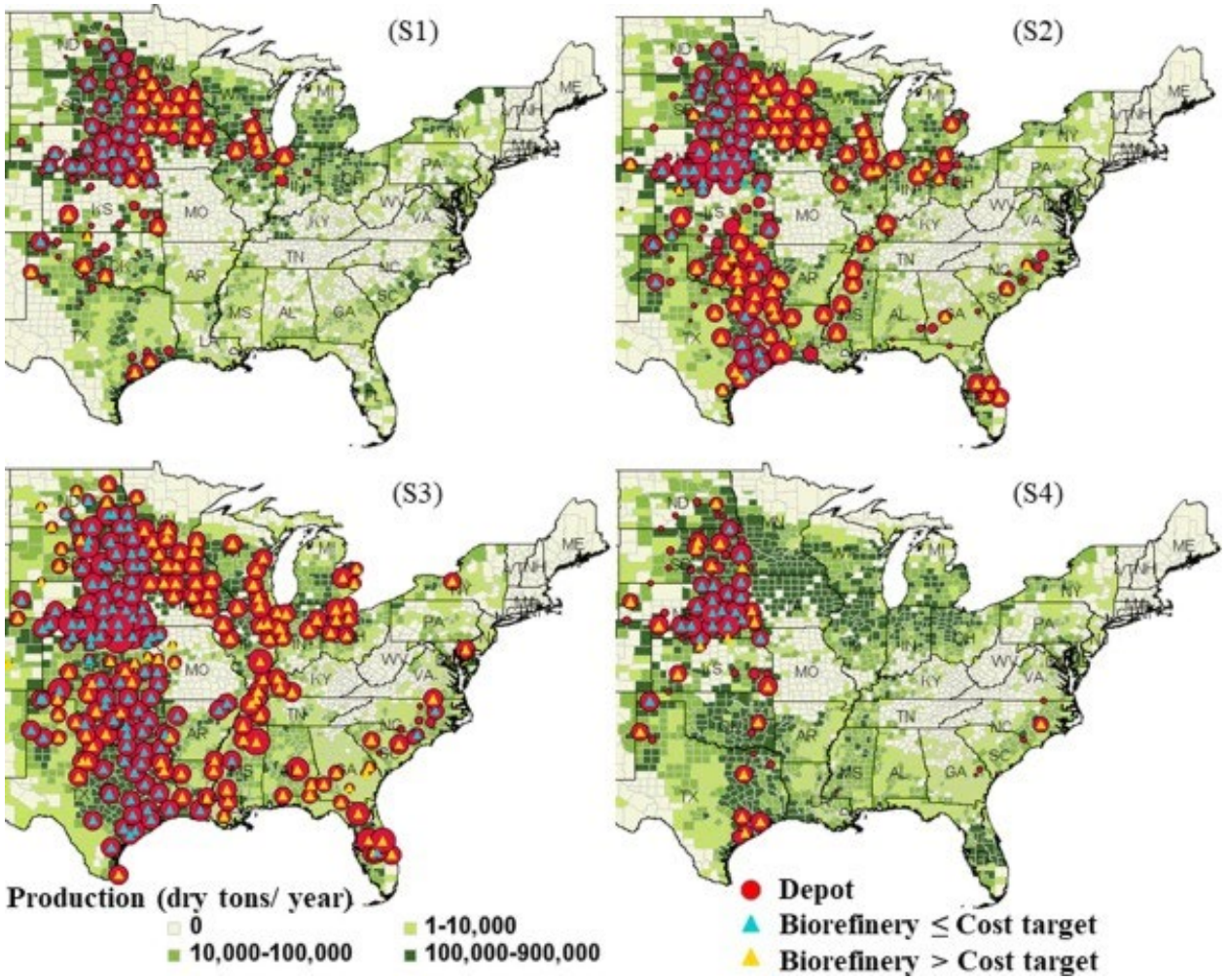
Greater than 90% of biomass feedstock material must meet all conversion specifications

Key Preprocessing Operations at INL



Nationwide Resource Mapping and Supply Chains

- Models predict cost, quality, and quantity nationwide
- Models optimize depot and biorefinery siting based on resource availability
- Supply chain costs consider harvest, collection, storage, transportation, and preprocessing operations
- Facilities utilize a mix of inexpensive and expensive feedstocks to attain an average cost under a determined threshold



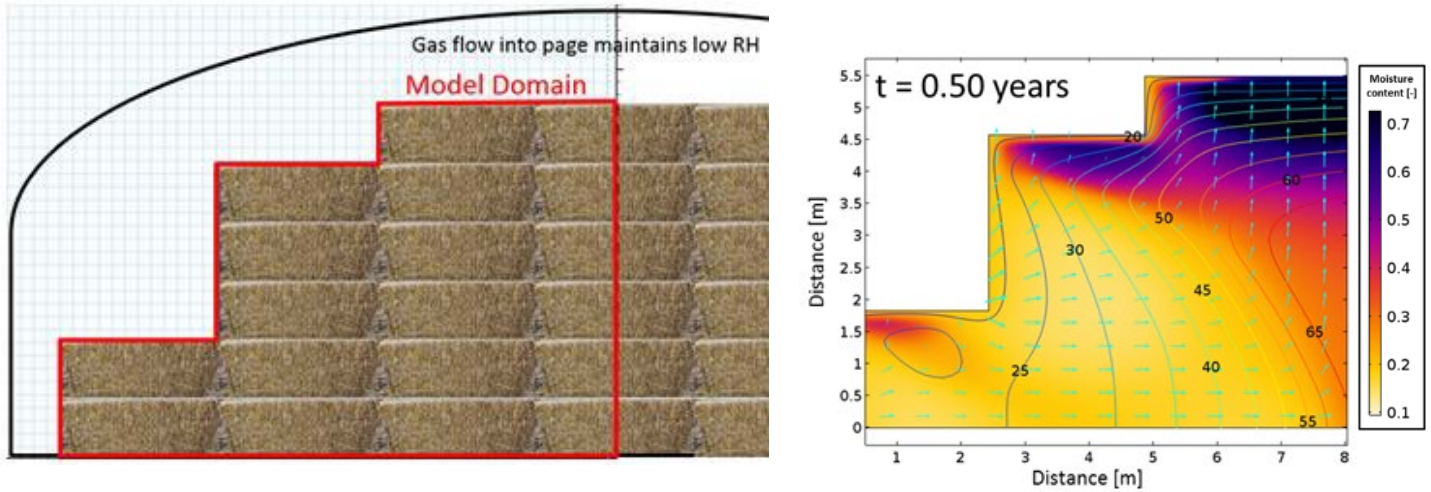
Hossain et. al. 2021 *Applied Energy*. https://doi.org/10.1016/j.apenergy.2021.116946

Moisture Is a Failure Point for the Industry and Must Be Managed

- Moisture moves during storage; biodegradation follows moisture, leading to spatial and temporal problems
  - Biological effects (microorganisms)
  - Chemical effects (hydrolysis, secondary reactions)
  - Physical effects (temperature swings, particle size, brittleness/fines generation)
- Goal: Develop technologies that reduce variability and degradation in harvested biomass to enable downstream utilization
- Every % dry matter loss in storage is estimated to cost $0.40/ton

Moisture Management Is Possible with Dry Systems

- Goal: Capture microbially-generated heat in service of carbon retention and value-added drying supporting the needs of downstream processes
- Breakthrough: Dry matter loss was reduced from 12% to 4% when corn stover was dried from 30% to 19% (wet basis) during storage



Modeling Efforts Inform Field Design for Stability

Moisture Is an Opportunity for the Industry and Can be Managed

- Storage can be used as a value-add to exploit residence time to perform slow physical and chemical transformations
- Anaerobic storage facilitates preservation in high moisture biomass and algae
  - Applicable to food and municipal wastes

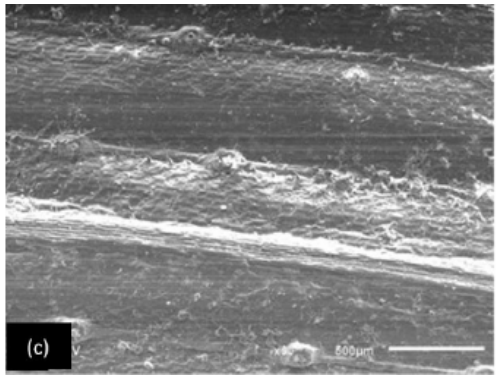
Silage tube and bagger

Drive over silage pile

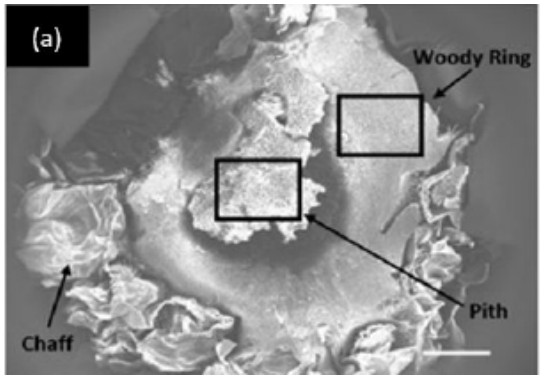
Preserved microalgae

Variability is Inherent to Herbaceous Biomass

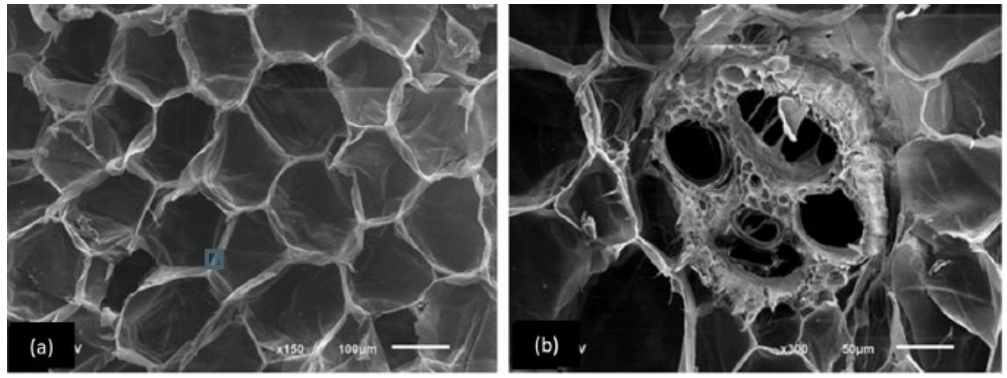
- Anatomical fractions have variable response in mechanical and chemical processing
  - Leaves are pulverized upon impact
  - Husks and stalk need shear-based size reduction



Corn stover leaves



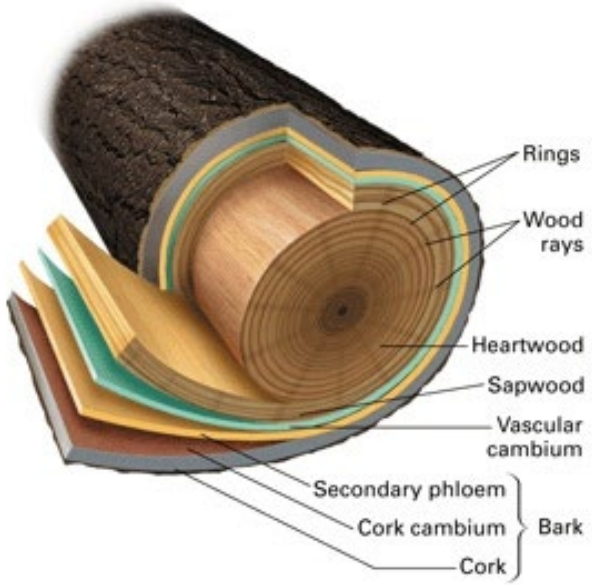
Corn cobs

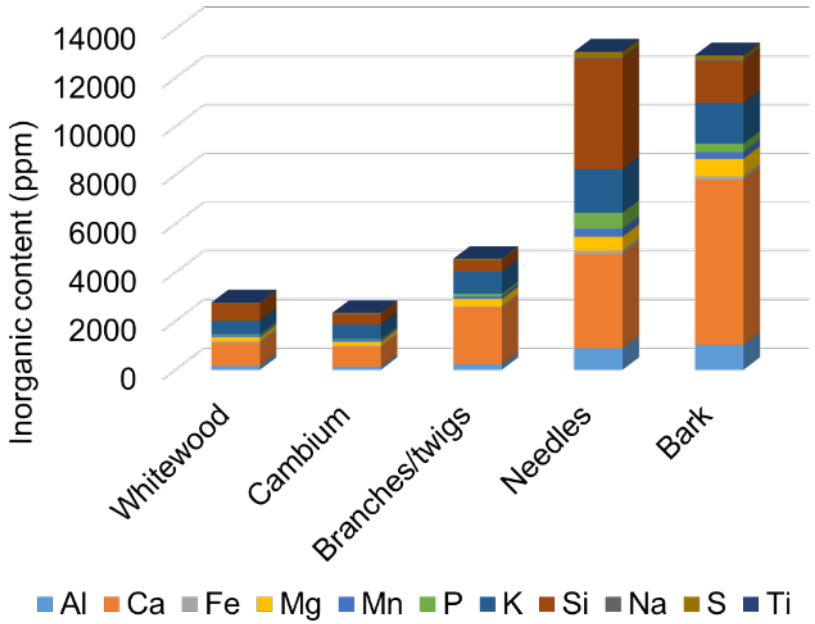


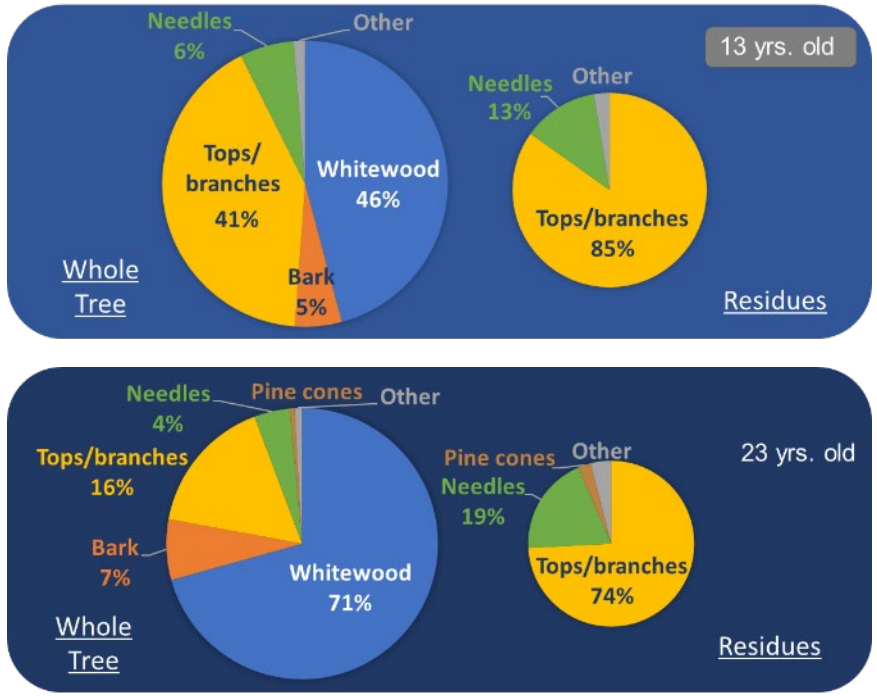
Corn stover stalks

Li et al., 2020, *ACS Sus. Chem. Eng*

Anatomical Fractionation is Critical to Achieve Conversion Specifications







- Wood has many anatomical fractions with significant differences in ash concentration
  - Ash causes challenges in conversion

Quality can be Managed with Preprocessing

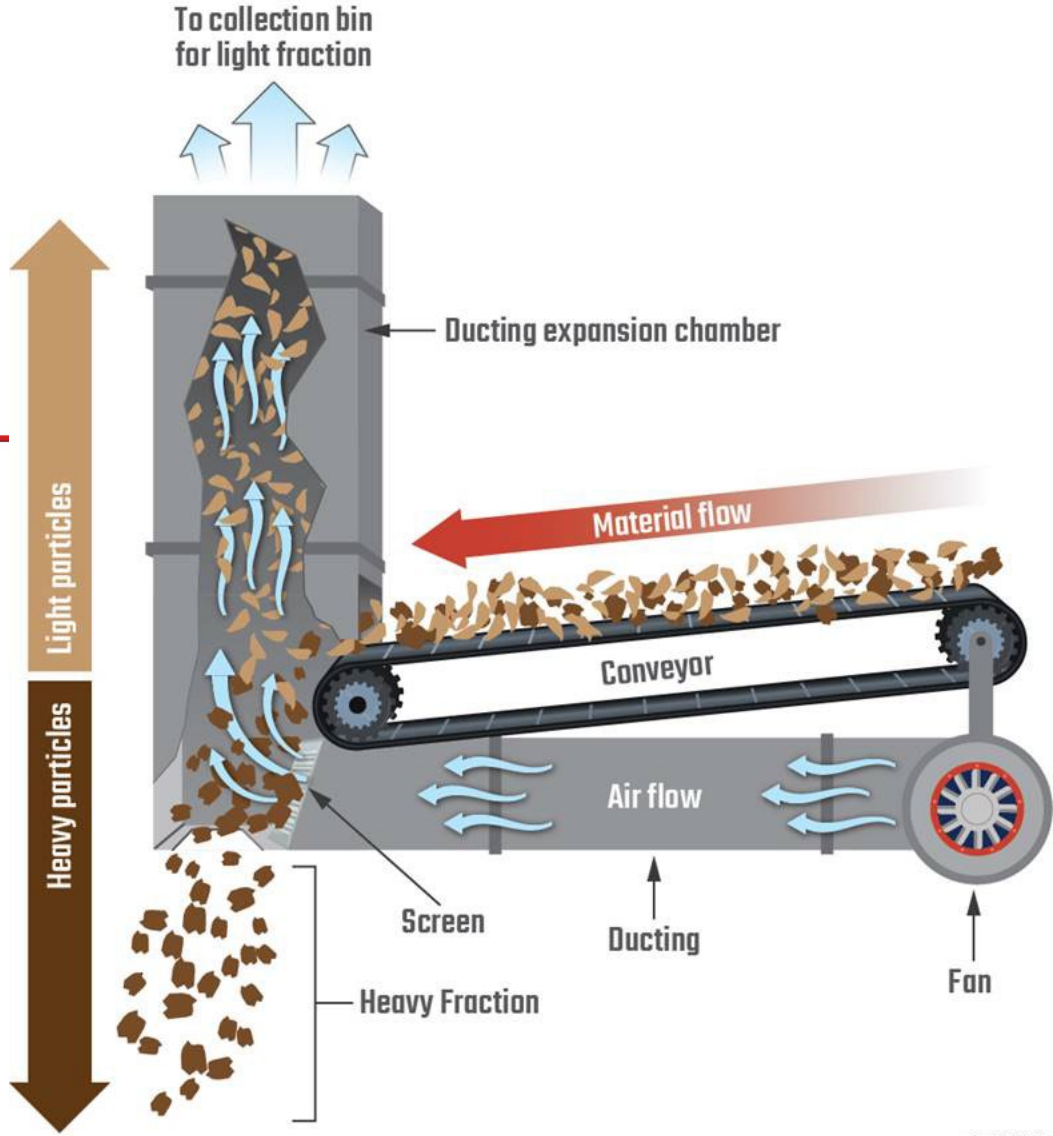
Forest Residue

White Wood

Bark

Needles

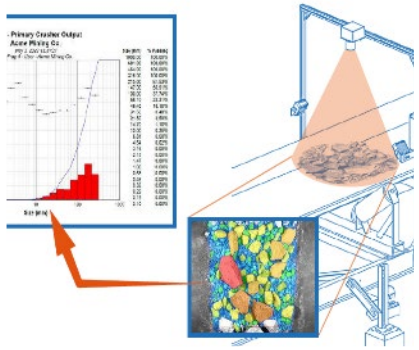
Forest residues can now be **separated into almost pure anatomical fractions** that will **reduce fines generation** and energy consumption in downstream milling operations



Real-Time Process Control to Reduce Energy Needs

- **Goal:** Develop artificial intelligence based, real-time process control software; improve drying efficiency of low-temperature biomass dryer
- On-line sensors measure feedstock properties such as moisture and particle size in real time
- Process controller gives feedback and modifies operation of dryer

Saw dust



Particle size measurement sensors

Non-contact moisture sensors

Vibrating fluid bed dryer

Reconfigurable Fractional Milling Loop

- Multi-stage comminution and separations
  - Removal of soil
  - Separation of husks and leaves
  - Recycle to achieve a narrow size distribution
- Reconfiguration enables tailored fractionation for multiple feedstocks and conversion pathways

High Moisture Pelleting Produces Dense, Flowable Products

Fractional milling: Increase screen size of stage-1 grinder and insert separator between stage-1 & 2 grinding operations to bypass fraction which meets stage-2 grinder specs

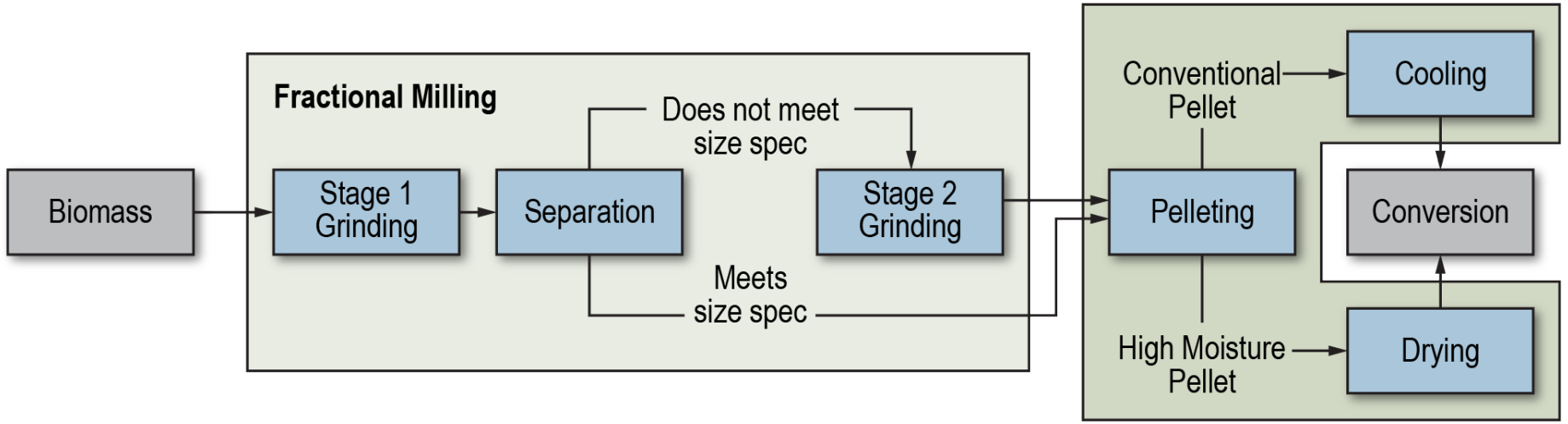
- Avoids redundant preprocessing and saves energy

High-moisture pelleting: Biomass is pelleted at moistures 18%–30% (w.b.).

- Biomass loses moisture (5%–10%, w.b.) due to preheating and frictional heat in the die

Low-temperature drying: High-moisture pellets can be dried using grain and belt dryers

- Less energy and capital intensive



Demonstrated the advanced preprocessing technologies using commercial-scale system at INL

1-Slide Guide to the FCIC

The Feedstock-Conversion Interface Consortium (FCIC) is led by the U.S. Department of Energy as a collaborative effort among researchers from nine national laboratories.

Key Ideas

- Biomass feedstock properties are **variable** and **different** from other commodities.
- **Empirical** approaches to address these issues have been **unsuccessful.**

The FCIC uses **first-principles-based science** to **de-risk** biorefinery scale-up and deployment by understanding and mitigating the impacts of **feedstock variability** on bioenergy conversion processes.

Argonne NATIONAL LABORATORY

BERKELEY LAB

INL Idaho National Laboratory

Los Alamos NATIONAL LABORATORY EST. 1943

NETL NATIONAL ENERGY TECHNOLOGY LABORATORY

NREL NATIONAL RENEWABLE ENERGY LABORATORY

OAK RIDGE National Laboratory

Pacific Northwest NATIONAL LABORATORY

Sandia National Laboratories

fcic FEEDSTOCK-CONVERSION INTERFACE CONSORTIUM U.S. DEPARTMENT OF ENERGY

energy.gov/fcic

Summary

- INL's capabilities range from feedstock logistics, preprocessing, and modeling spanning bioenergy supply chain
  - Biomass Feedstock National User Facility designated in 2013
- Feedstock quality specifications are critical to maximizing predictability of conversion
- As industry moves to more diverse resources such as MSW, wet wastes, and gaseous feedstocks to support a circular carbon economy, more emphasis is needed to reduce variability in:
  - Flowability and handling
  - Fractionation (critical to maximizing revenue)
  - Stability
- **Feedstock management is critical to biorefinery performance**

Acknowledgments

- This work is supported by the U.S. Department of Energy's (DOE's) Office of Energy Efficiency & Renewable Energy, Bioenergy Technologies Office, under DOE Idaho Operations Office Contract DE-AC07-05ID14517.

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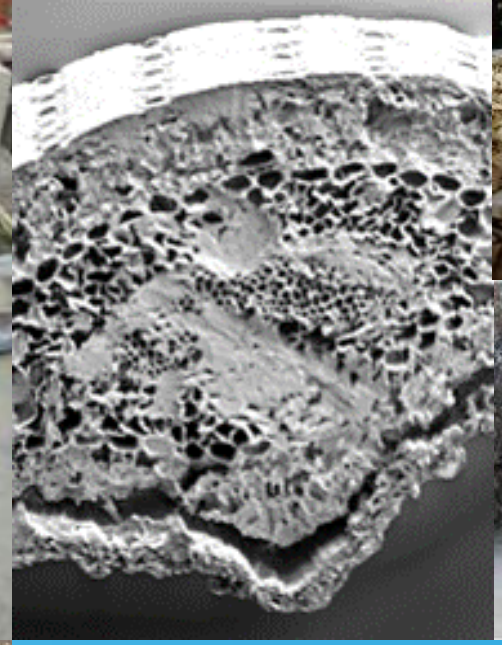



Challenges and Solutions for Working with Wastes at the Biomass Feedstock National User Facility

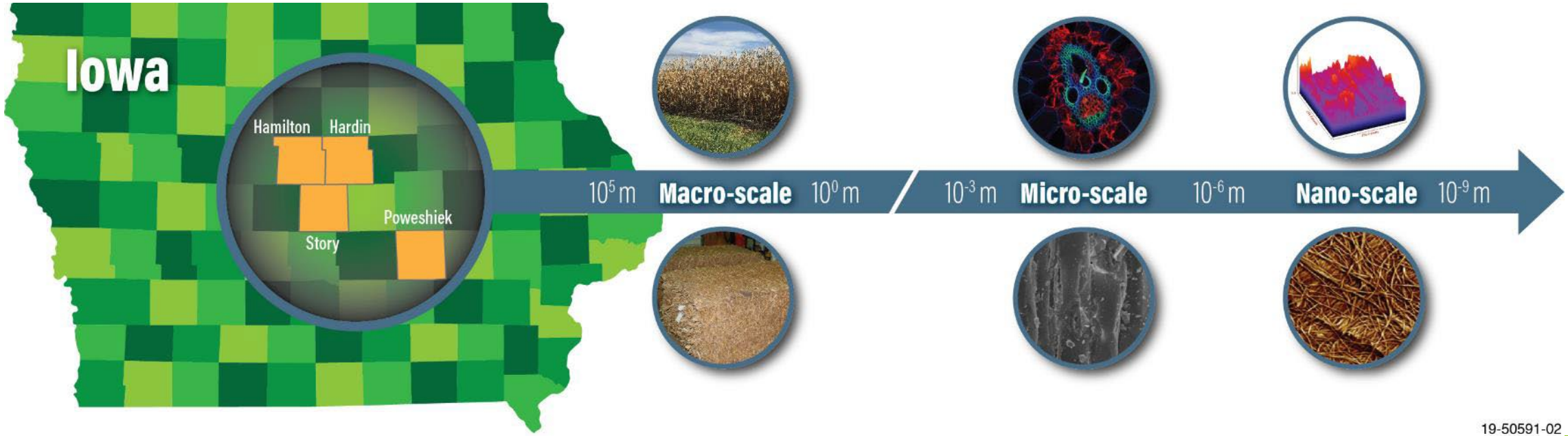
Idaho National Laboratory

BFNUF Capabilities Across Multiple Scales

BFNUF helps us understand types of variability in feedstock (define feedstock) and develop processes to manage and respond to it.

Quality by Design (QbD) approach

- Develops products with specific quality attributes from raw materials
- Understanding variability is fundamental to developing processes that manage and respond to it.

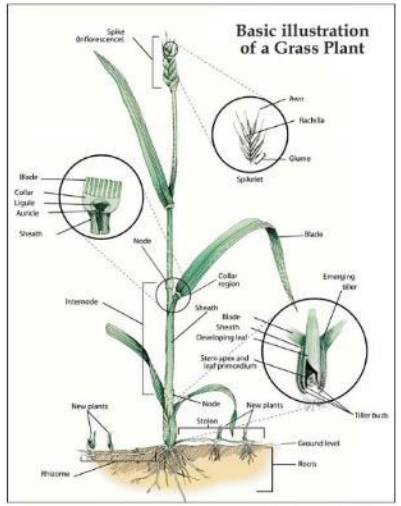


19-50591-02

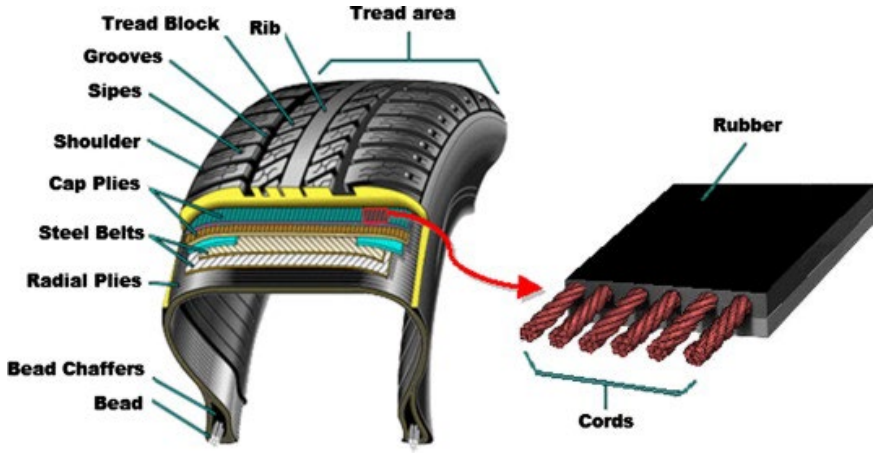
Ray et al., **2020,** *ACS Sus. Chem. Eng.*

Developing New Processes for New Feedstocks

How do we accelerate process innovation for evolving waste streams?



Preprocessing targeted for anatomical fractions

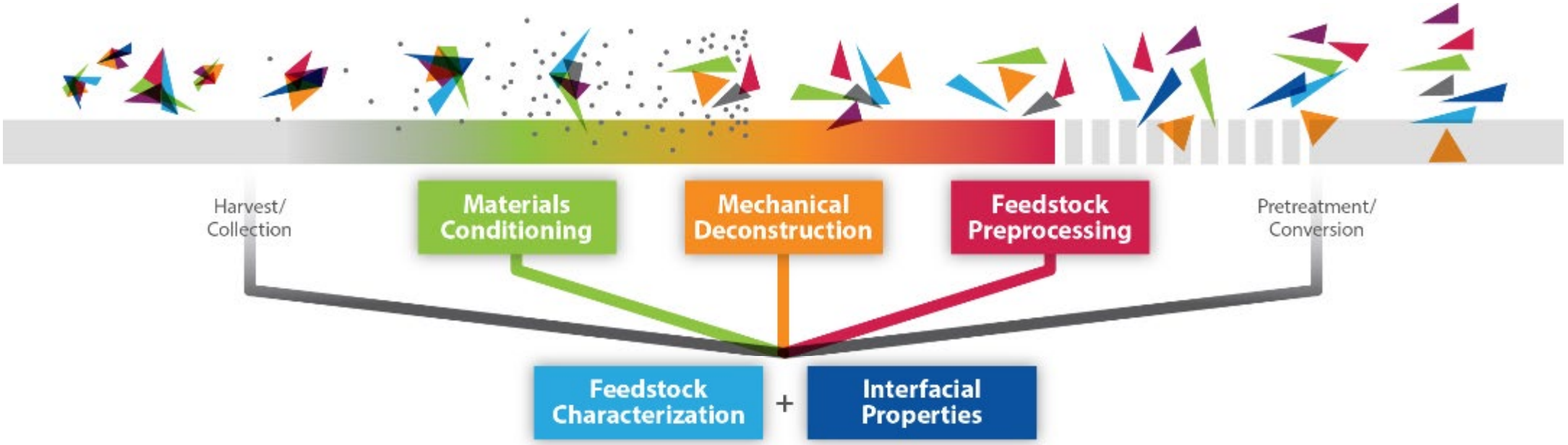


Advanced separation techniques recover original parts for upcycling

High-fidelity sorting and robust conversion processes

Mitigating Risk from Beginning to End

- Flexible preprocessing options
- Analytical and computational capabilities to augment science-based understanding
- Reduce scale-up risk of larger production failure

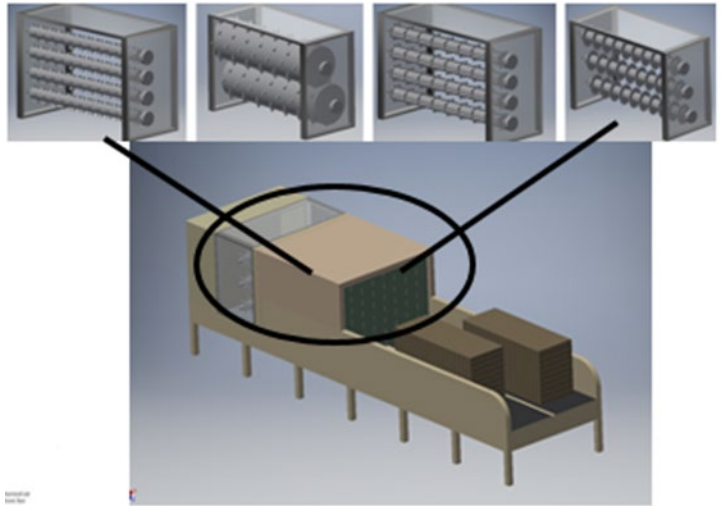


Feedstock Preprocessing

Scale-up of technologies involving mechanical deconstruction and fractionation of waste materials, like difficult-to-handle multilayered composites, into circular economy feedstocks

General Capabilities

Material Introduction



Size Reduction

Impact

High aspect ratio

Shear

Uniform aspect ratio

Separations

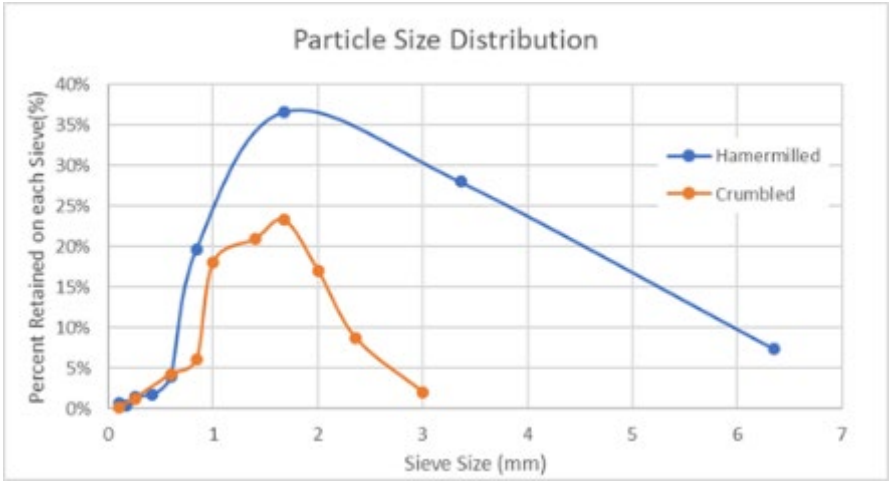
Feedstocks processed at the industrially relevant bale scale and can be investigated for value-added co-products and appropriately sampled for small scale tests.

New Size Reduction and Separations Enable Cob Fractionation

Pith density	Rind density	Chaff density
223 kg/m^3	67 kg/m^3	45 kg/m^3

Work with partner institutions will evaluate the impact of these separations on conversion technologies like enzymatic deconstruction and pyrolysis

Sieving Techniques Control Size Distribution



Fundamental Deconstruction and Handling

BFNUF performs small-scale studies on deconstruction using specific tools to:

- Develop purer separation results.
- Better understand material handling challenges.
- Improve success of technology at a larger, industrial scale.

General Capabilities

Deconstruction Mechanisms

Mill	Impact	Attrition	Shear	Compression
Condux	Primary		Secondary	
Tornado	Primary			
Vibrating Ball		Secondary		Primary
Attrition		Primary	Secondary	
PolarFit				Primary
Disc Refiner			Primary	Secondary

Handling & Densification

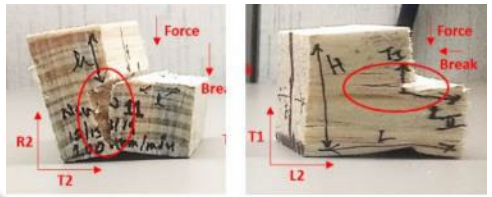
Screw Extruder

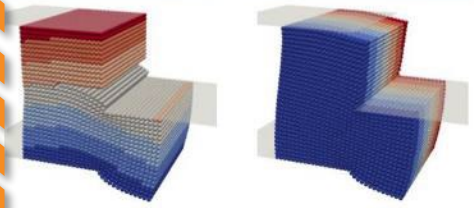
Fluidized Bed Agglomerator

Experiments Inform Computational Models

Macroscale model

Jordan Klinger & Yidong Xia (INL)

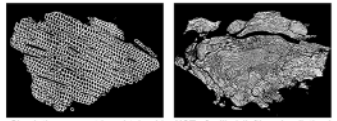




A bonded-sphere DEM method with nonlinear strain-hardening and breakage models

Microscale model

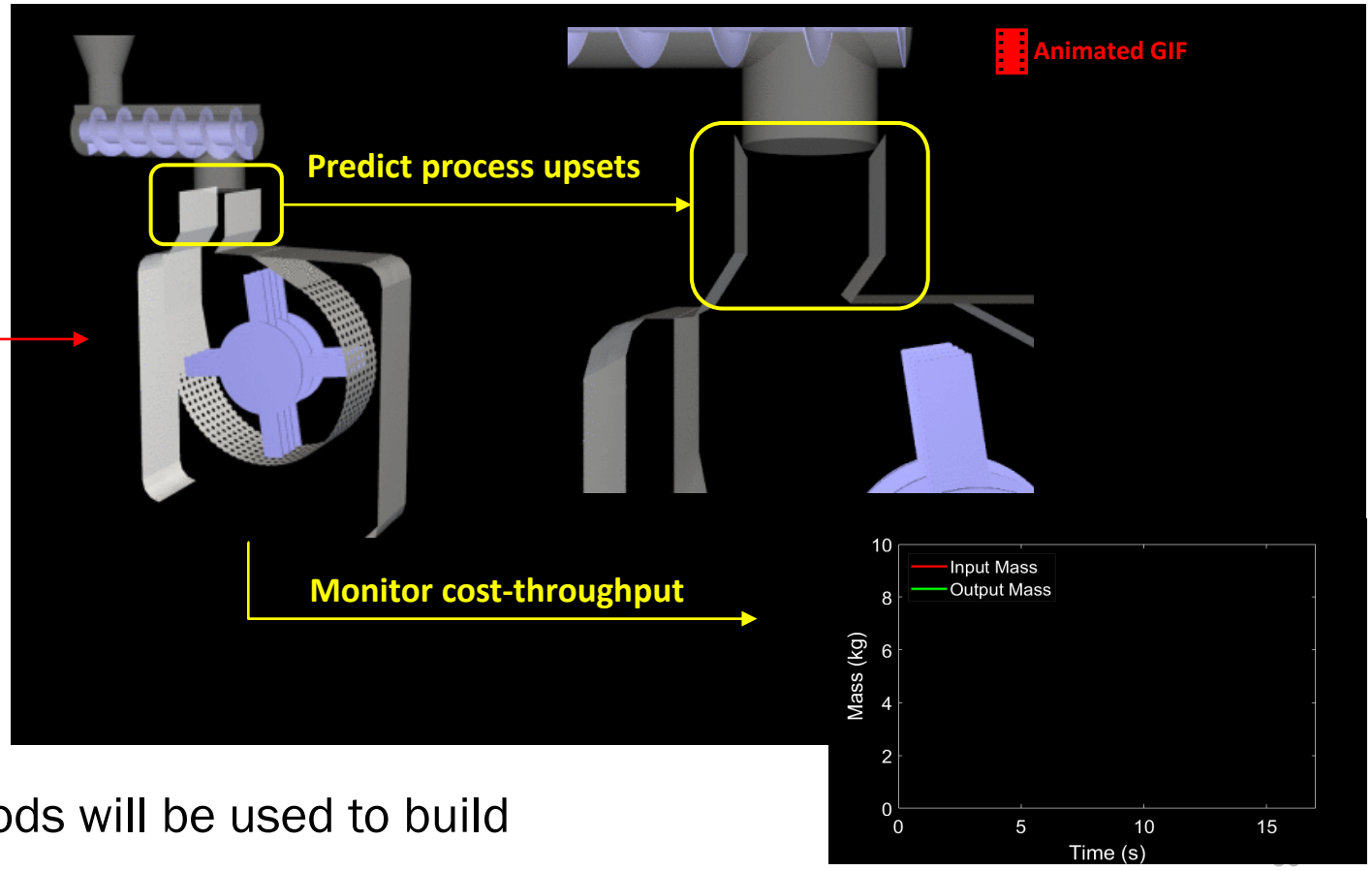
(NREL)



Simulation geometries obtained by XCT of milled (left) and pelletized (right) pine showing differences in microstructure and porosity

Physics-based modeling informs optimal feeding & preprocessing

Yidong Xia & Jordan Klinger (INL) and university partners



New deconstruction and densification methods will be used to build new particle breakage models.

Materials Conditioning Capability

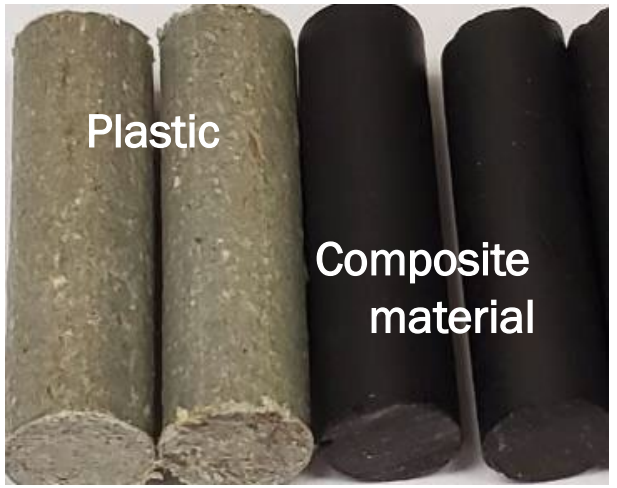
Treating the material with moisture, heat, chemicals, or pressure helps reduce material variability later in the conversion process.

General Capabilities

Environmental Storage

Moisture Modification

Tempering

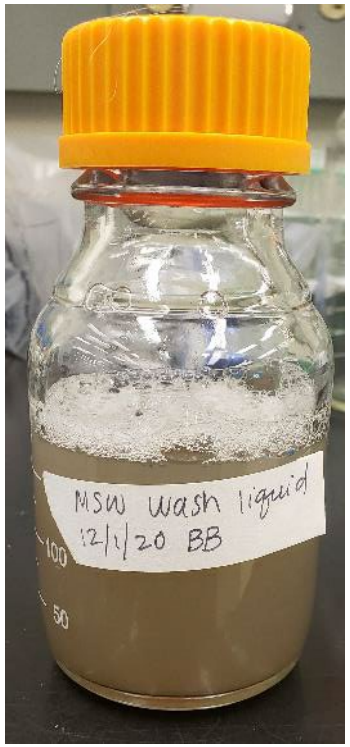


This capability aims to reduce downstream material variability for improved process reliability and generation of co-products at a variety of scales.

Plastic Decontamination Studies

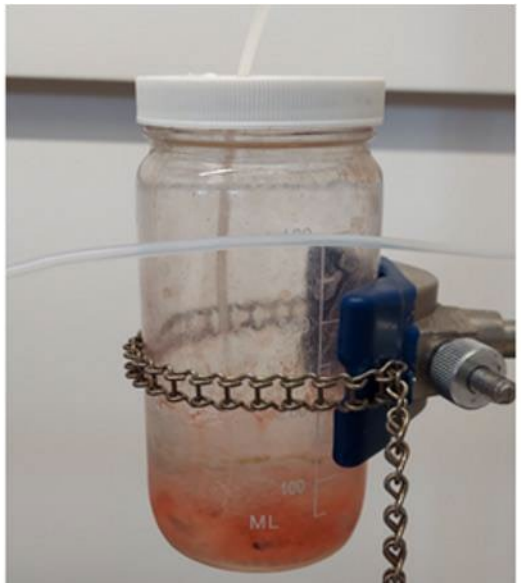
Detergent wash

Samples washed with detergent and water



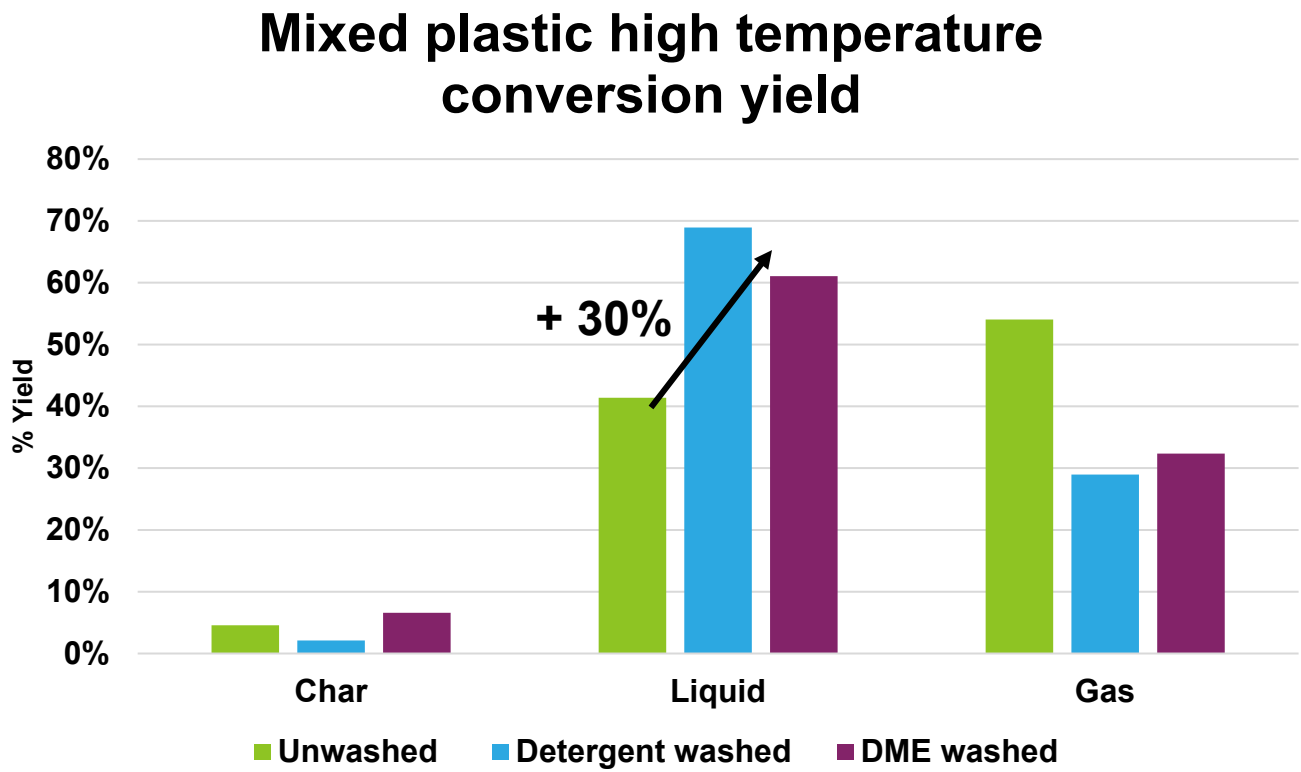
Chemical wash

Samples washed with dimethyl ether (DME)



Rebecca M. Brown, Amber N. Hoover, Jordan L. Klinger, Bradley D. Wahlen, Damon Hartley, Hyeonseok Lee, Vicki S. Thompson.
Decontamination of Municipal Solid Waste Increases Low and High Temperature Conversion Yields
Submitted to Frontiers Energy Research

Decontamination Increases the Yield



Liquid oil yield was **increased by almost 30%** when plastic was washed with detergent and DME.

Rebecca M. Brown, Amber N. Hoover, Jordan L. Klinger, Bradley D. Wahlen, Damon Hartley, Hyeonseok Lee, Vicki S. Thompson.
Decontamination of Municipal Solid Waste Increases Low and High Temperature Conversion Yields
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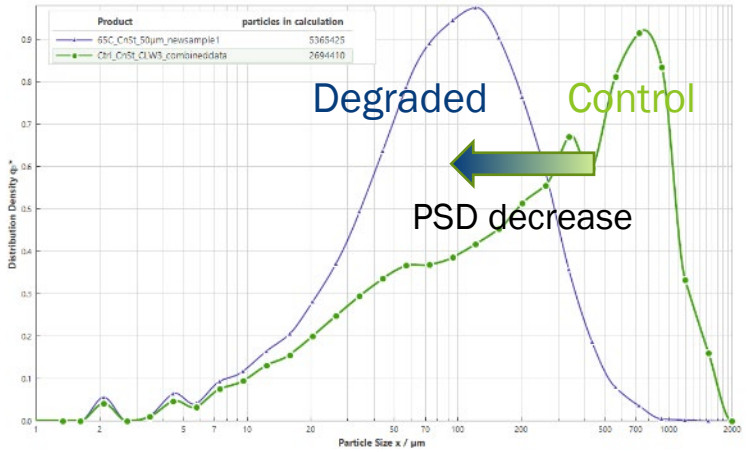
Feedstock Characterization Capability

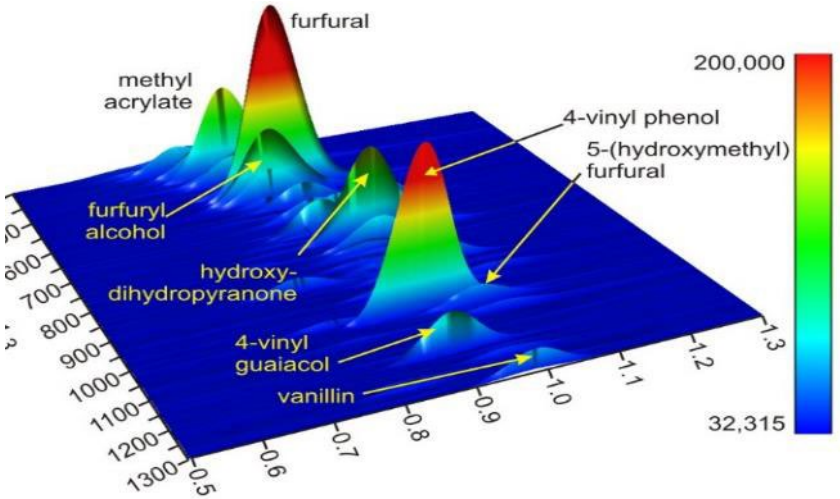
Builds characterization capabilities to help industry identify important properties to measure

General Capabilities

Chemical and Particle Characterization



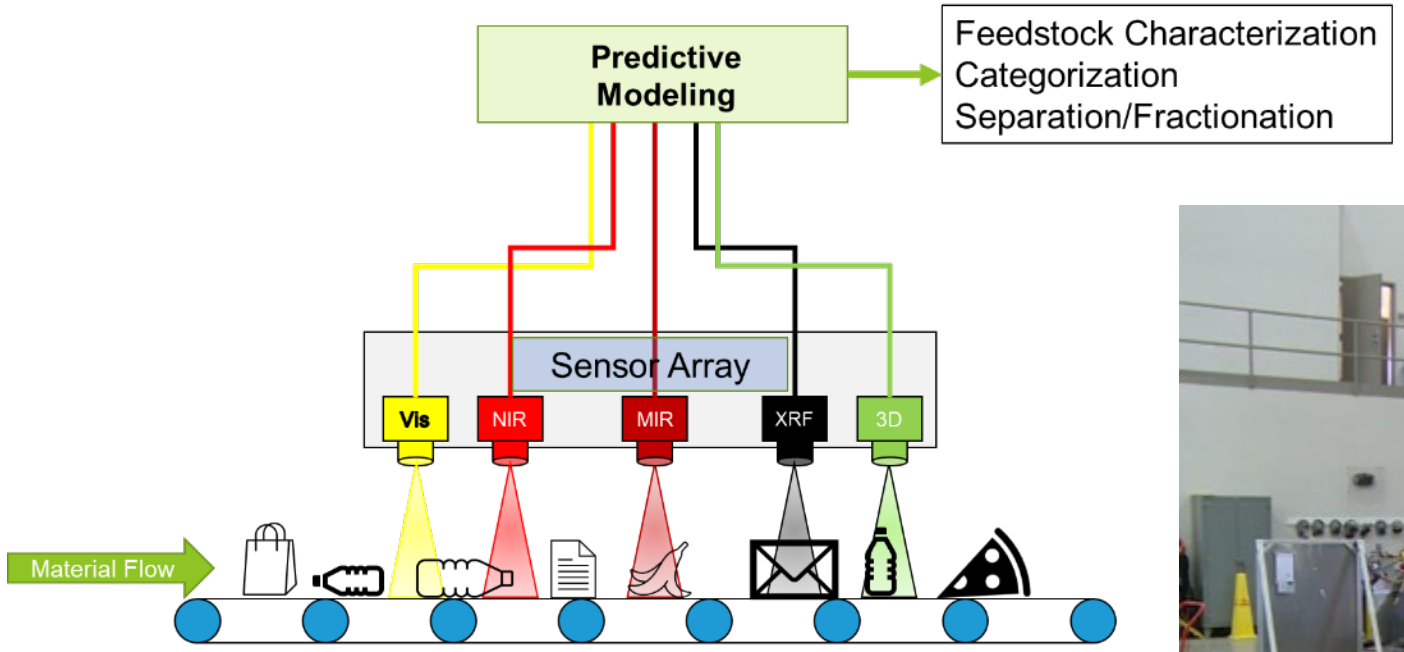
Reactivity Screening



Chemical Signature Separation

These characterization capabilities will be used across all scales of tests to help enable a quality by design approach to feedstock development.

New Spectroscopic Analysis Tools will Improve Robotic Separations



New tools, like Mid-IR, cameras will allow us to better characterize plastics in MSW for separations using artificial intelligence-based software.

Interfacial Properties

Builds fundamental understanding of solid-solid and solid-liquid interfaces to figure out how composite layers and densified materials as well as individual particles impact handling.

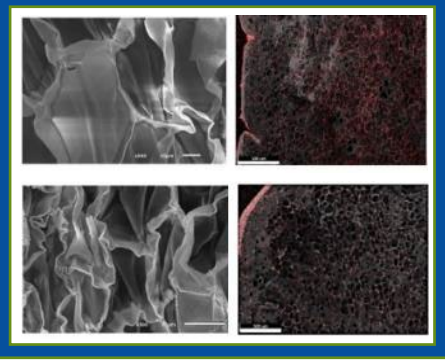
General Capabilities

Interfacial Biological and Chemical Properties

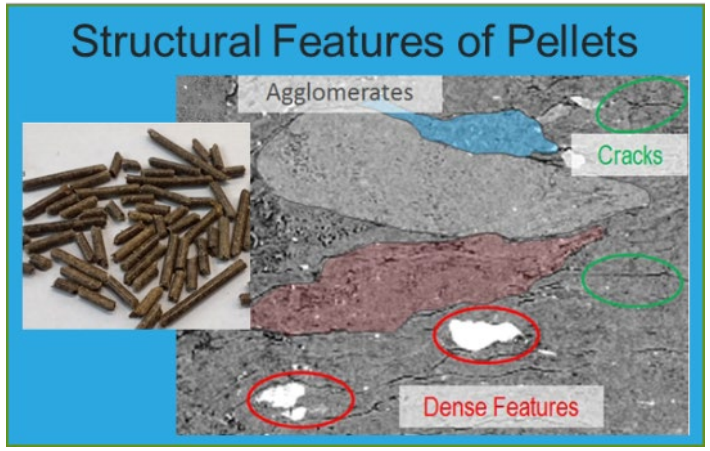
Inorganics more concentrated in pith than rind (pink Si)

Mild degradation

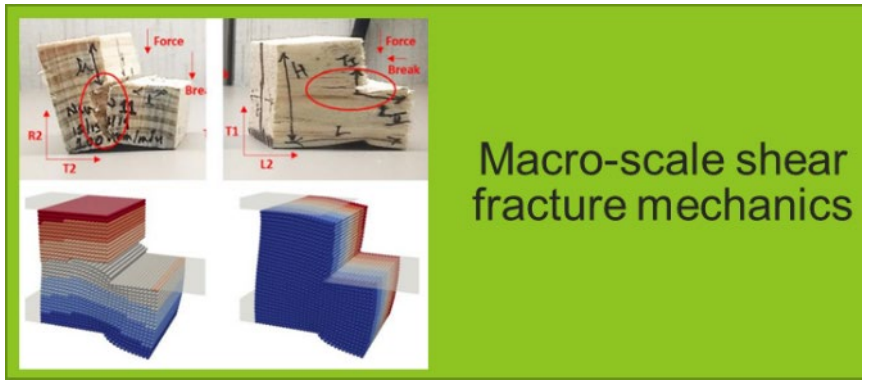
Severe degradation



Multiscale Structure

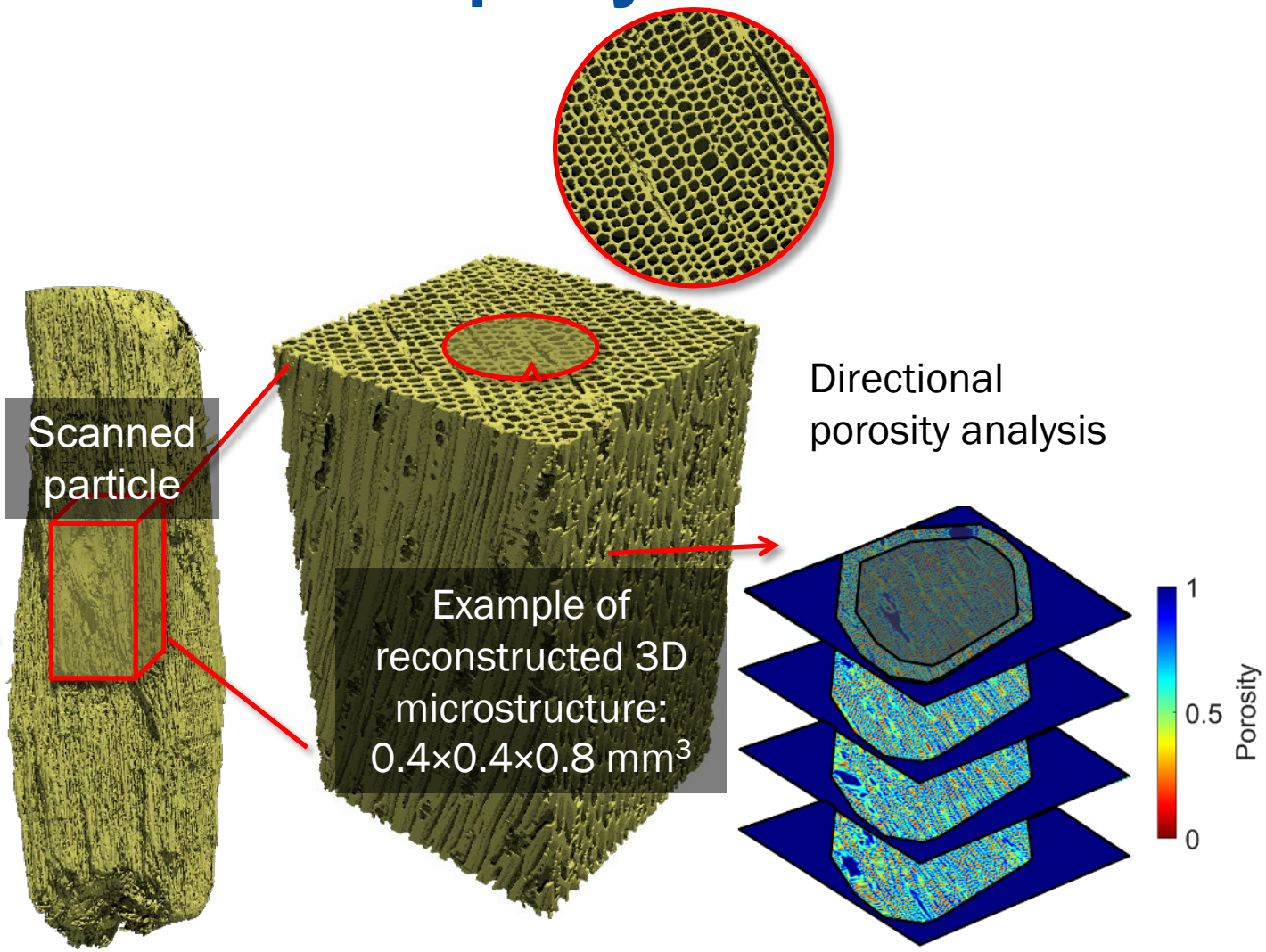


Multiscale Mechanical Properties



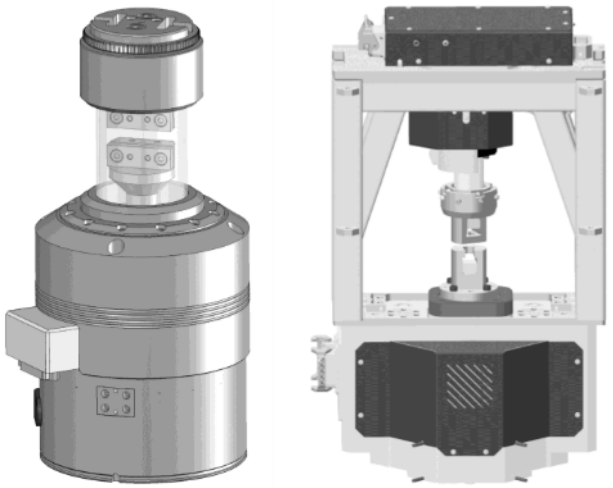
This capability will leverage characterization tools across INL to look at properties that impact storage, separations, handling, and conversion across scales.

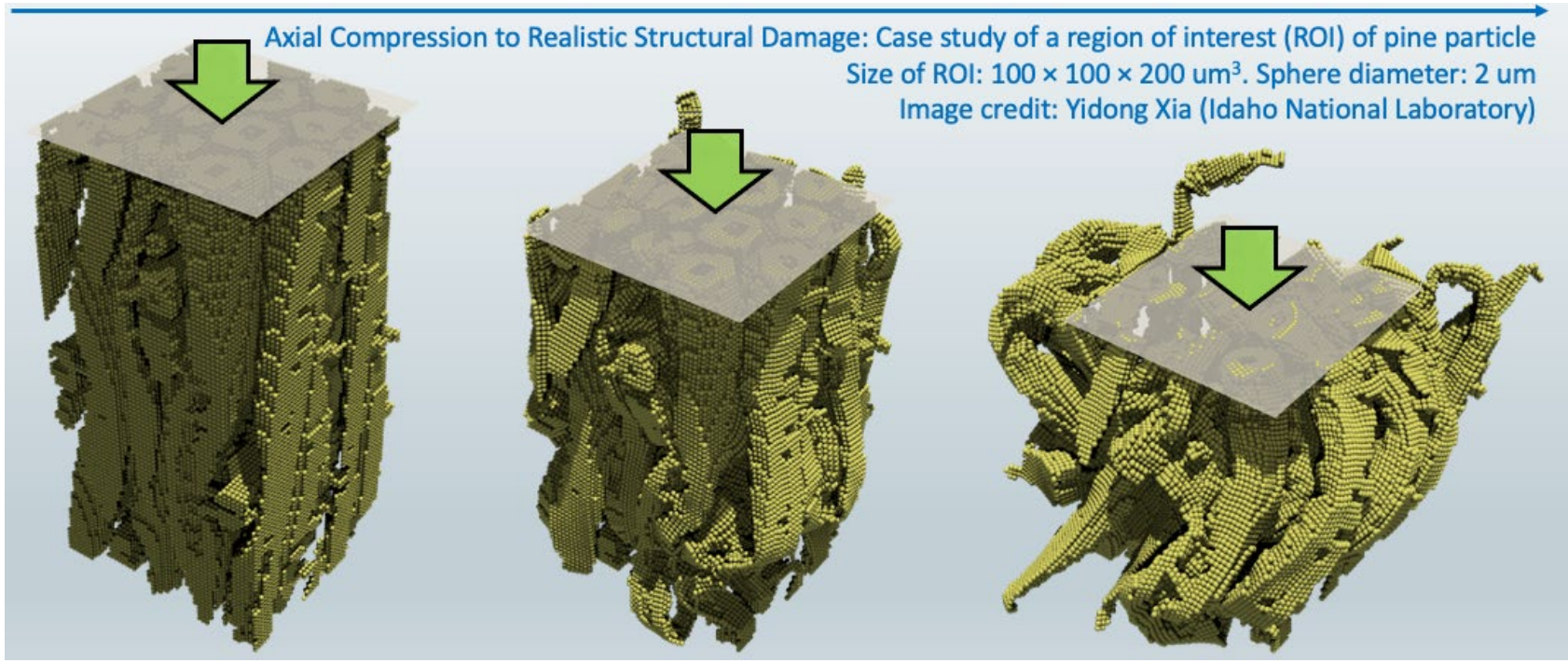
Environmental In-situ X-Ray CT and Micromechanics Model for Feedstock Particle Property Characterization



Quan Sun, Yidong Xia, Jordan Klinger, Robert Seifert, Joshua Kane, Vicki Thompson, Qiushi Chen, "X-ray computer tomography-based porosity analysis: Algorithms and application for porous woody biomass." *Powder Technology* 388 (2021): 496-504. https://doi.org/10.1016/j.powtec.2021.05.006

Environmental In-situ X-Ray CT and Micromechanics Model for Feedstock Particle Property Characterization

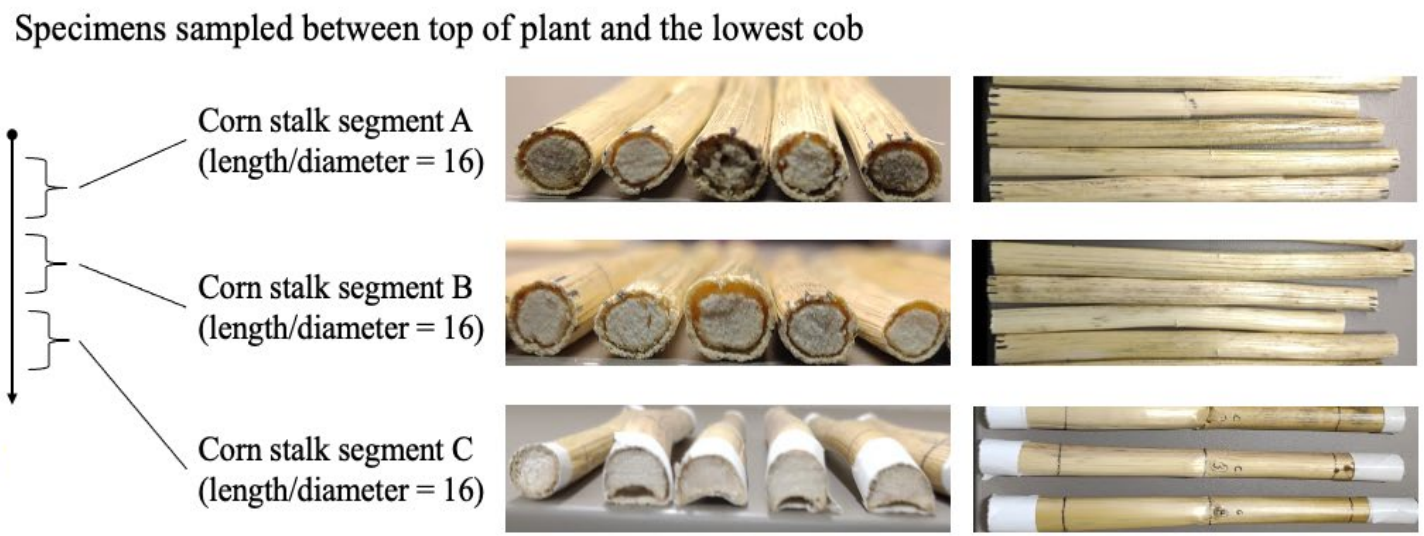


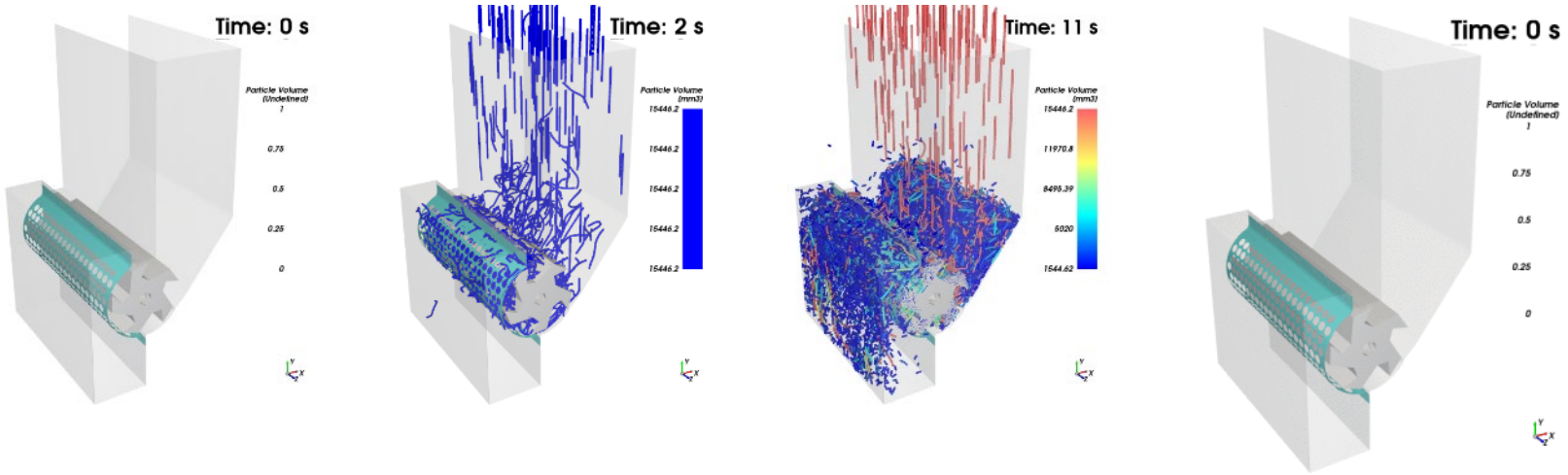


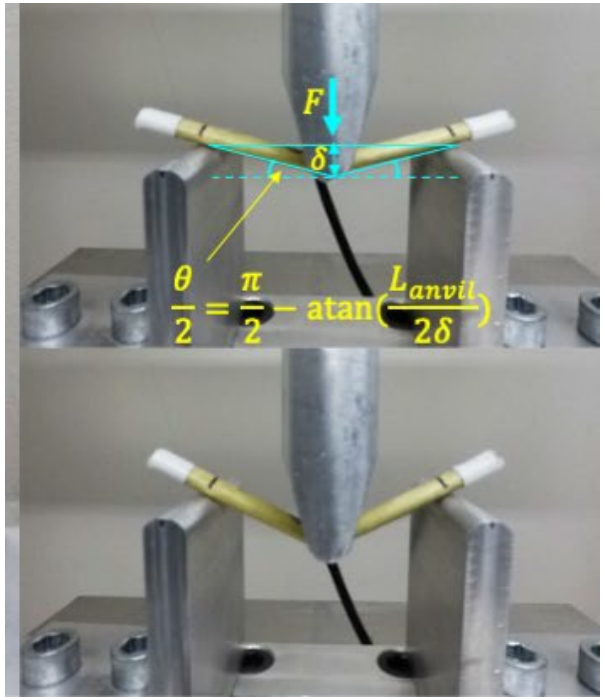
Environmental in-situ mechanical testing and modeling will be used to understand fundamental mechanisms in feedstock fracturing in comminution process.

Quan Sun, Yidong Xia, Jordan Klinger, Robert Seifert, Joshua Kane, Vicki Thompson, Qiushi Chen, "X-ray computer tomography-based porosity analysis: Algorithms and application for porous woody biomass." *Powder Technology* 388 (2021): 496-504. https://doi.org/10.1016/j.powtec.2021.05.006

High-Quality Feedstock Mechanical Characterization Enables High-Fidelity Comminution Unit Modeling







New benchmark bending test will provide data for developing high-fidelity predictive model of comminution process.

Yidong Xia, Jordan Klinger, Tiasha Bhattacharjee, Vicki Thomson, "The elastoplastic flexural behavior of corn stalks", submitted to *Biosystems Engineering* (under review) 2021

Recycling Challenge of Multilayered Packaging

Multilayer composite materials cannot currently be recycled because they are mixtures of various plastics and metals contaminated with pigments and dyes.

Key:
Blue: Polyethylene
Green: Polyethylene copolymer
Light Grey: Aluminium foil

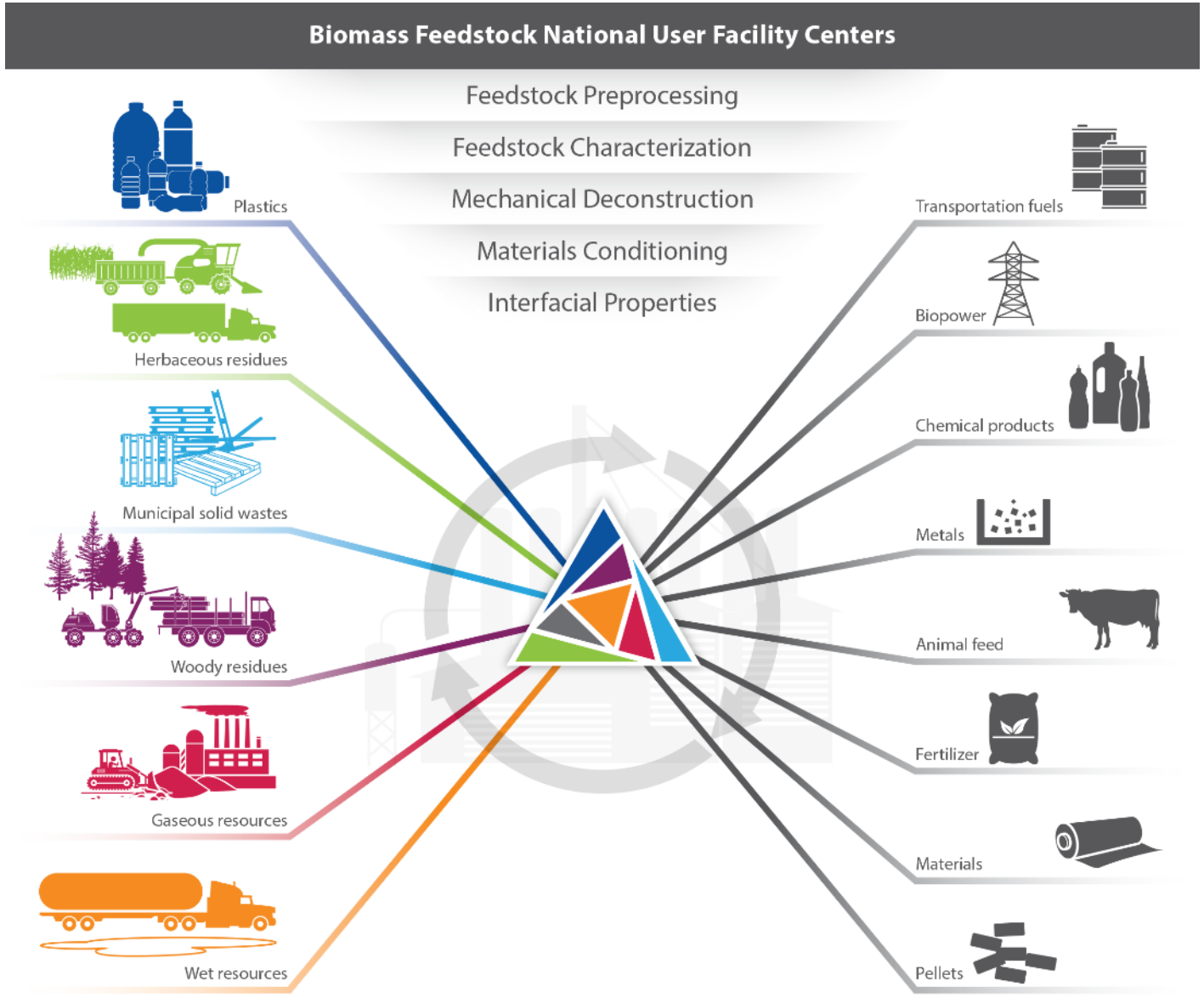
BFNUF capabilities aim to advance recycling methods for multilayered composite materials.

BFNUF Capabilities

1. Solve flowability challenges at a variety of scales to **create flexible feedstocks and processes**

2. Use wide ranging characterization and fractionation capabilities to **produce feedstocks that meet conversion specifications**

3. Facilitate the **transfer of innovative technologies to industry**



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Thank you!

Today's Presentation:

Biomass Feedstock Supply Challenges and Solutions with Idaho National Laboratory

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Dr. Luke Williams
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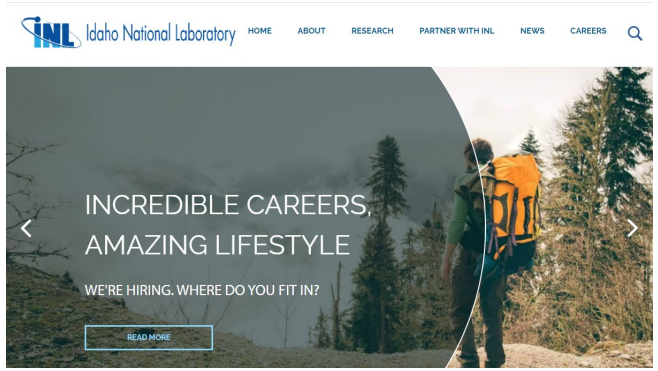
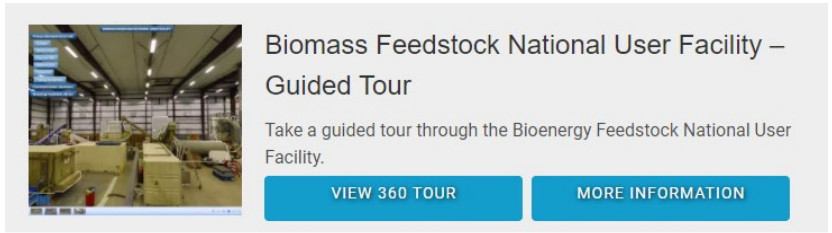


Idaho National Laboratory Website
inl.gov



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