DOE Bioenergy Technologies Office (BETO)
2023 Project Peer Review

FCIC Task 2 – Feedstock Variability

April 6, 2023
Feedstock-Conversion Interface Consortium (FCIC)

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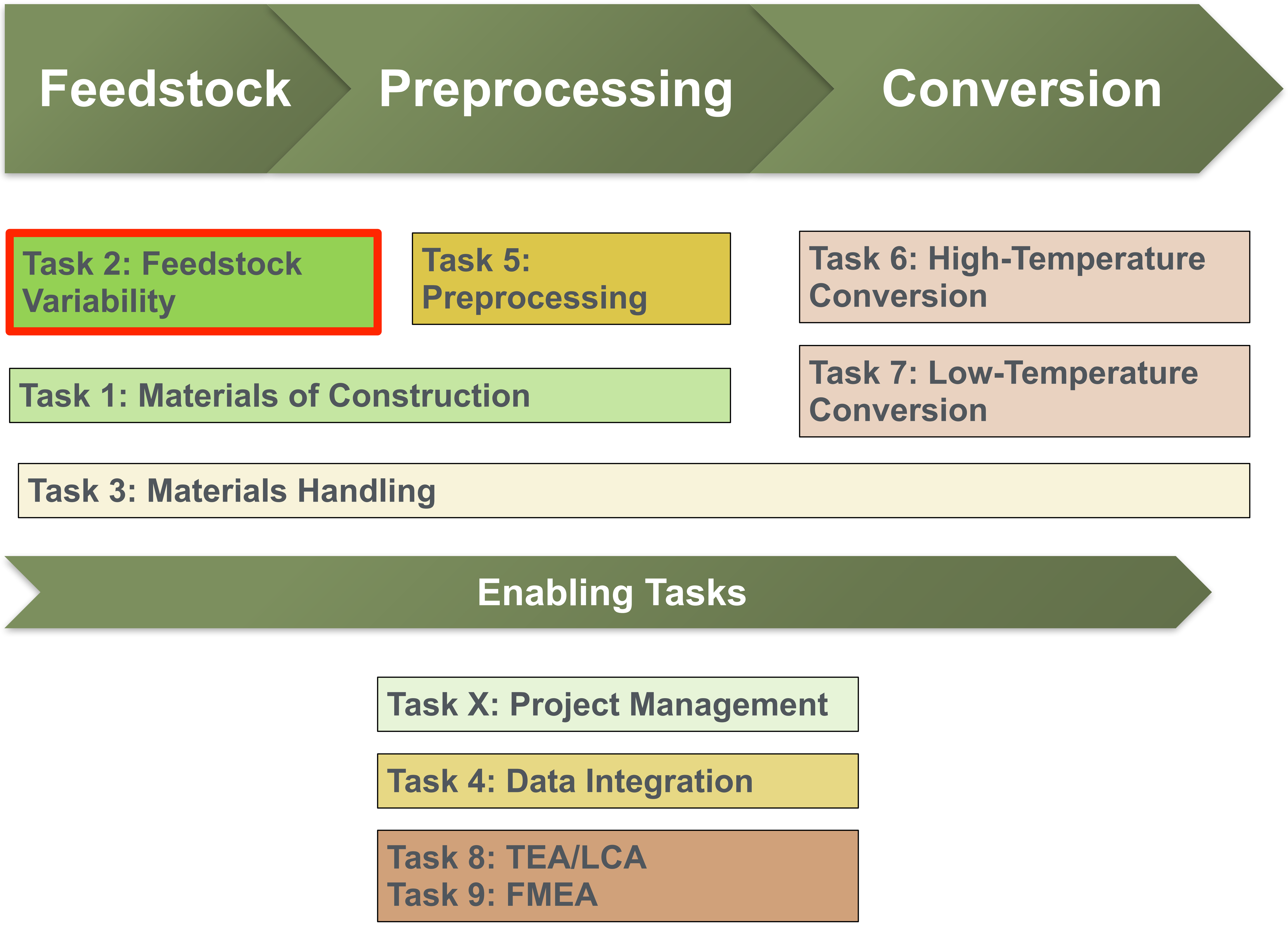
Project Overview

FEEDSTOCK-CONVERSION INTERFACE CONSORTIUM

U.S. DEPARTMENT OF ENERGY

FCIC Task Organization



- **Task X: Project Management:** Provide scientific leadership and organizational project management
- **Task 1: Materials of Construction:** Specify materials that do not wear or break at unacceptable rates
- **Task 2: Feedstock Variability:** Quantify and understand the sources of biomass resource and feedstock variability
- **Task 3: Materials Handling:** Develop tools that enable continuous, steady, trouble-free feed into reactors
- **Task 4: Data Integration:** Ensure the data generated in the FCIC are curated and stored; FAIR guidelines
- **Task 5: Preprocessing:** Enable well-defined and homogeneous feedstock from variable biomass resources
- **Tasks 6 & 7: Conversion (High- & Low-Temperature Pathways):** Produce intermediates for further processing
- **Task 8: Crosscutting Analyses (TEA/LCA):** Valuation of intermediate streams and quantify variability impact
- **Task 9: Failure Mode & Effects Analysis (FMEA):** Standardized approach for assessing attribute criticality

LCA: life cycle analysis; TEA: techno-economic analysis

Feedstock Variability

Objective:

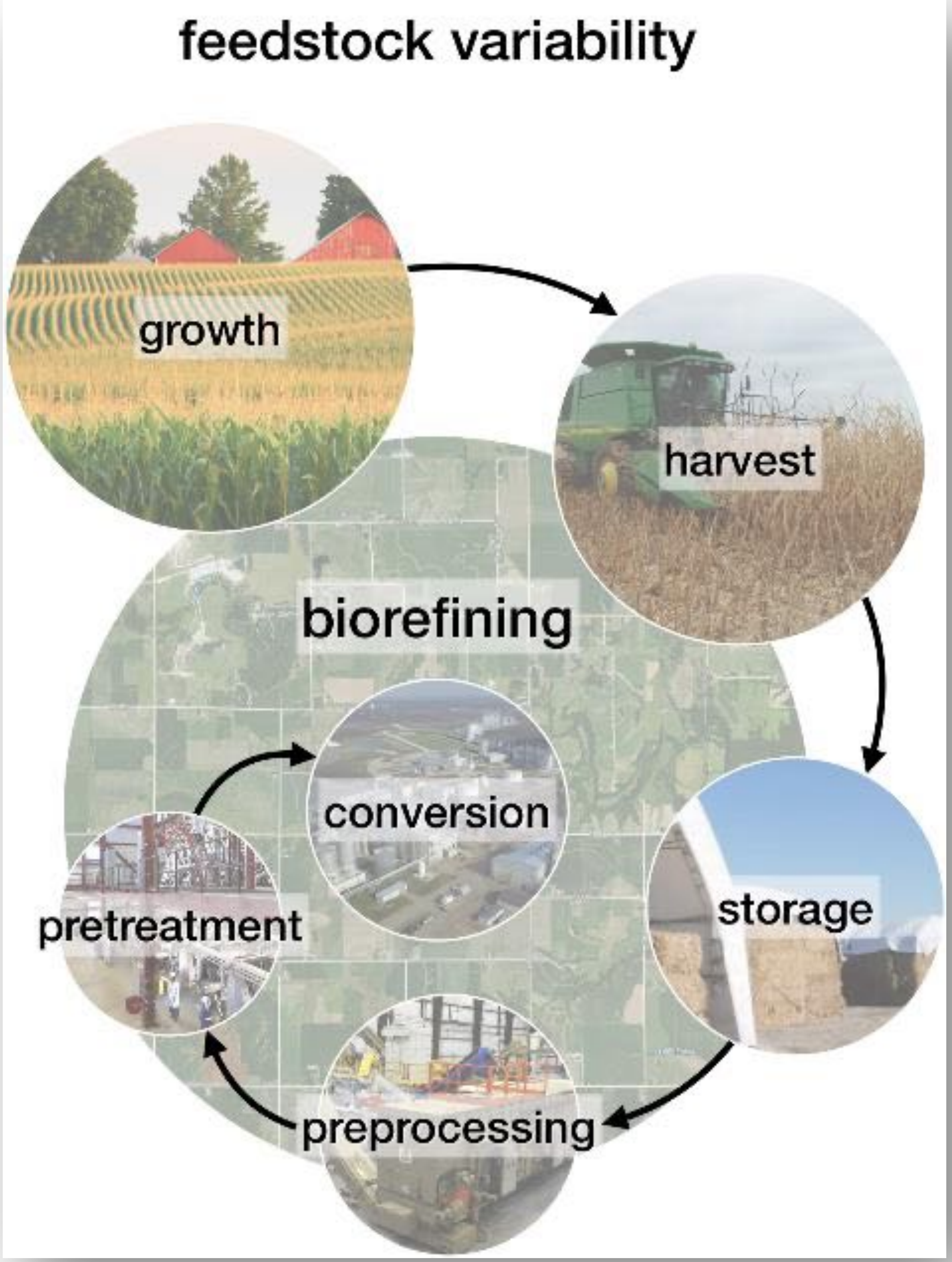
- Identify and quantify the **initial distribution of feedstock critical material attributes (CMAs)** and inform strategies to manage this variability.

Impact:

- **Characterization tools** and CMA **variability data** that inform (1) harvest and storage best practices, (2) feedstock quality, and (3) selection of processes to manage variability.
- Knowledge of the sources of **intrinsic vs. process-induced** variability.
- Feedstock suppliers, process designers, and equipment manufacturers can benefit from this **fundamental knowledge** of drivers that are critical to de-risking the industry.

Outcome:

- Understanding key **sources** of biomass variability (e.g., growth conditions, harvest conditions, storage degradation) to identify and quantify CMA **distributions** that propagate across unit operations to inform cost-effective management of variability.



Task 2 Quality by Design Summary

Unit Operation	CMA	Critical Process Parameter (CPP)	Critical Quality Attribute (CQA)
Feedstock growth	Drought impacts	Agronomics, silviculture	Harvest yield, anatomical ratios, composition
Feedstock harvest/ collection	Plant development	Low/high cut, crop/ plant age	Ash content, moisture, anatomical ratios
Feedstock storage	Moisture content	Storage time, storage design	Composition, structural integrity, moisture

icons from vecteezy.com

Feedstock Variability Team: Collaborating Across National Labs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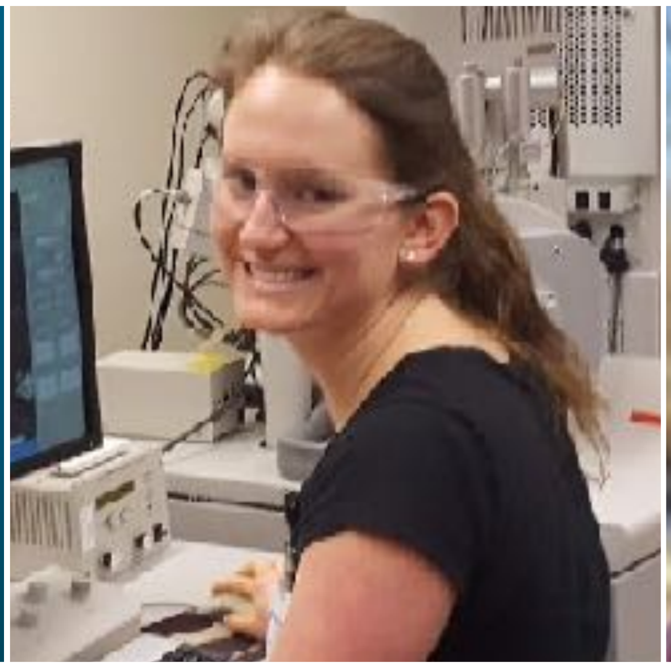
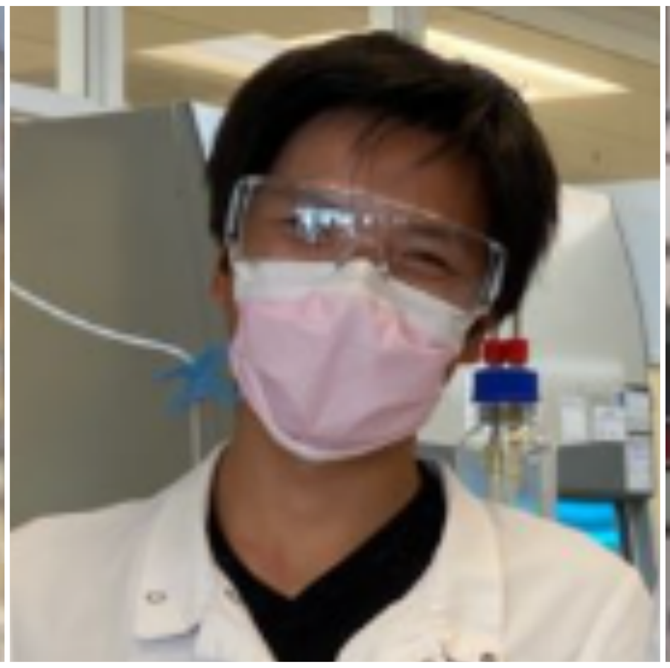
Mentoring a Diverse Next Generation of Bioenergy Advocates








Intern Name	R. Ace Aguilar	Chance Benedict	Elizabeth Bose	Caroline Frischmon	Tyler Pham	Sanjana Rathore
Level	Undergraduate	Undergraduate	Undergraduate	Undergraduate	High school	High school
Original Institution	University of California, Berkeley	University of North Texas & USMC	Virginia Tech	Univ. of Minnesota	American High School	Mission San Jose High School
Current Institution	Stanford University	Kansas City Univ. Osteopathic Medicine	CIA & American University	University of Colorado, Boulder	Santa Clara University	Mission San Jose High School

1 – Approach

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Technical Approach:

- **Multiscale characterization to identify and understand feedstock variability** focused on how the structural and physicochemical attributes of cell wall architecture and biomass tissues underlie flow behavior and mechanical, and thermochemical deconstruction.
- Coupling advanced characterization, analytical tools, and data analytics to quantify properties that **reveal CMAs and explain the origins of their variability.**

Challenges:

- Developing **robust characterization** beyond traditional compositional analysis, bulk moisture, total ash, and particle size distribution.
- Establishing the **criticality** of feedstock attributes.

Metrics:

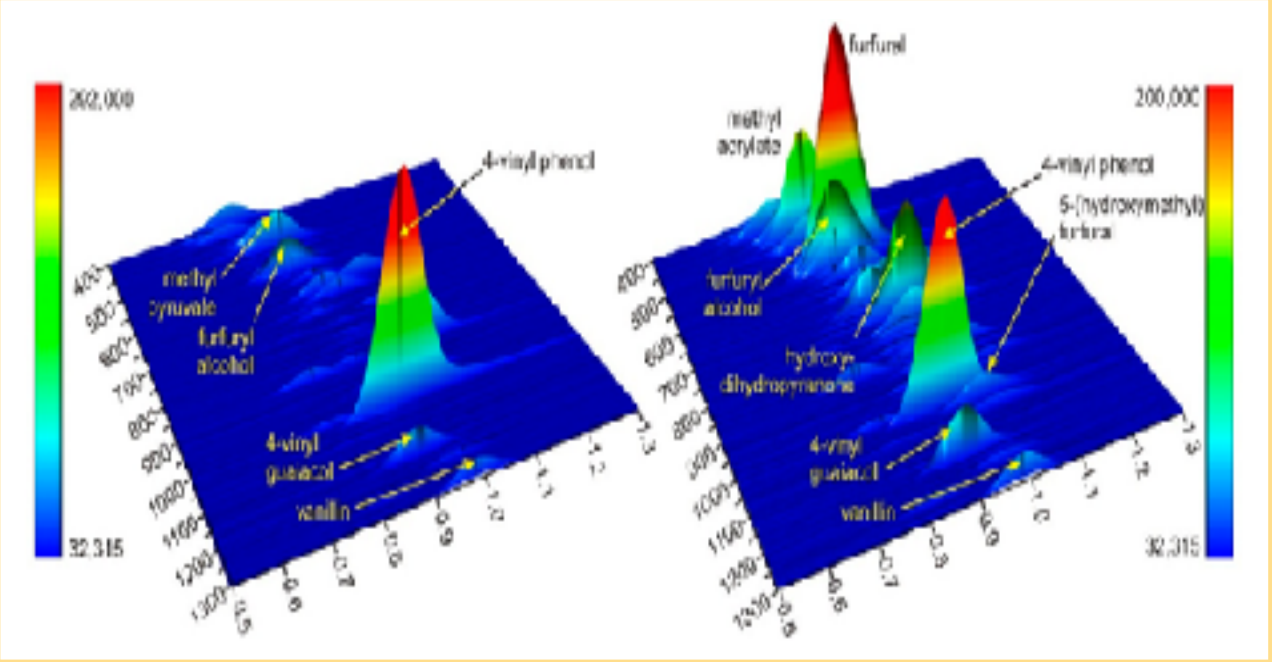
- **Knowledge and tools** for the characterization of variability at multiple scales.
- Foundations of an **attribute-driven approach** for feedstock quality management.

Risks/Mitigation Strategies:

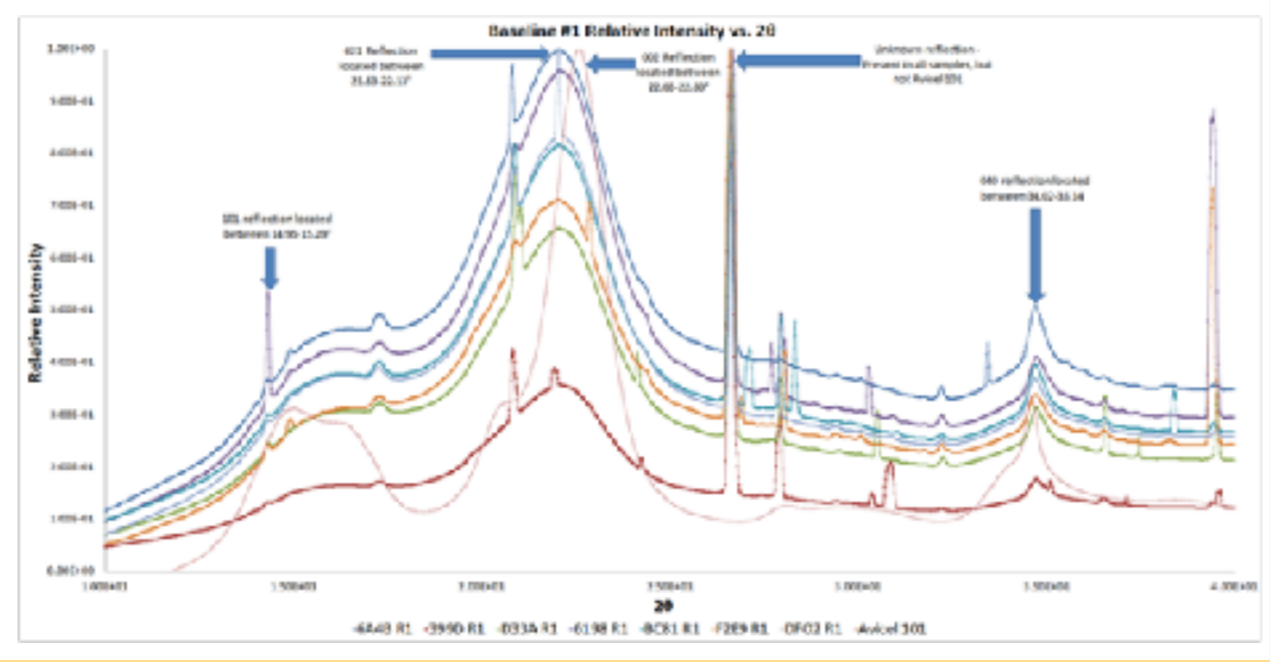
- Lack of data, understanding of **attribute-impact relationships**, and task integration.
- Mitigation by coupling **fundamental characterization and data-driven approaches** and harnessing the diverse capabilities of an interdisciplinary, multi-institution team.

Advanced Chemical and Physical Characterization

Cell wall polymer structure

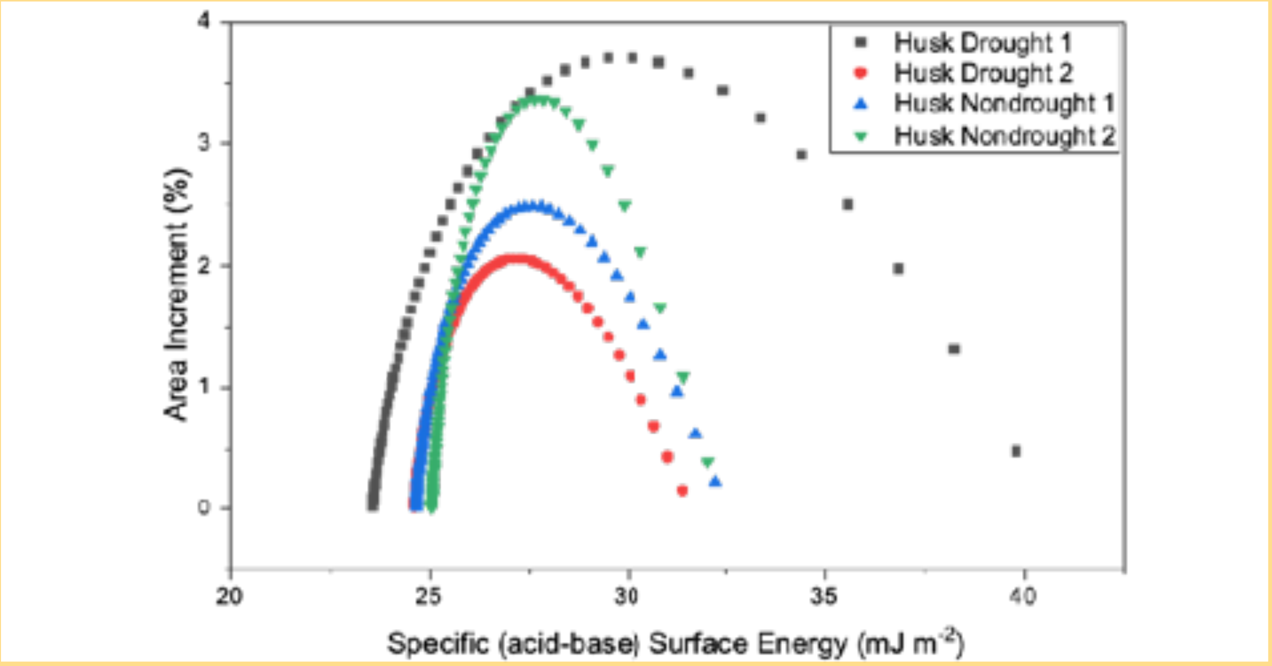


Pyrolysis–gas chromatography–mass spectrometry (Py-GC*GC/MS)
- Identify compounds in bio-oils generated from biomass pyrolysis

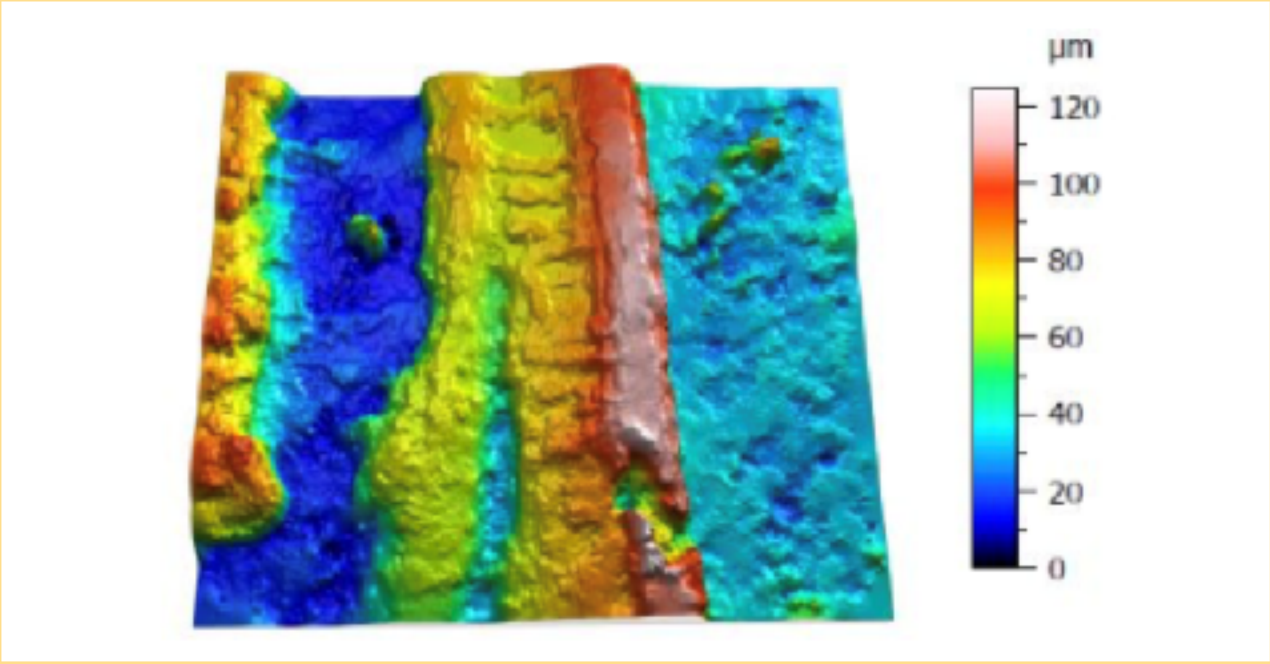


X-ray diffraction
- Determine polymer architecture and quantify cellulose crystallinity

Particle surface properties

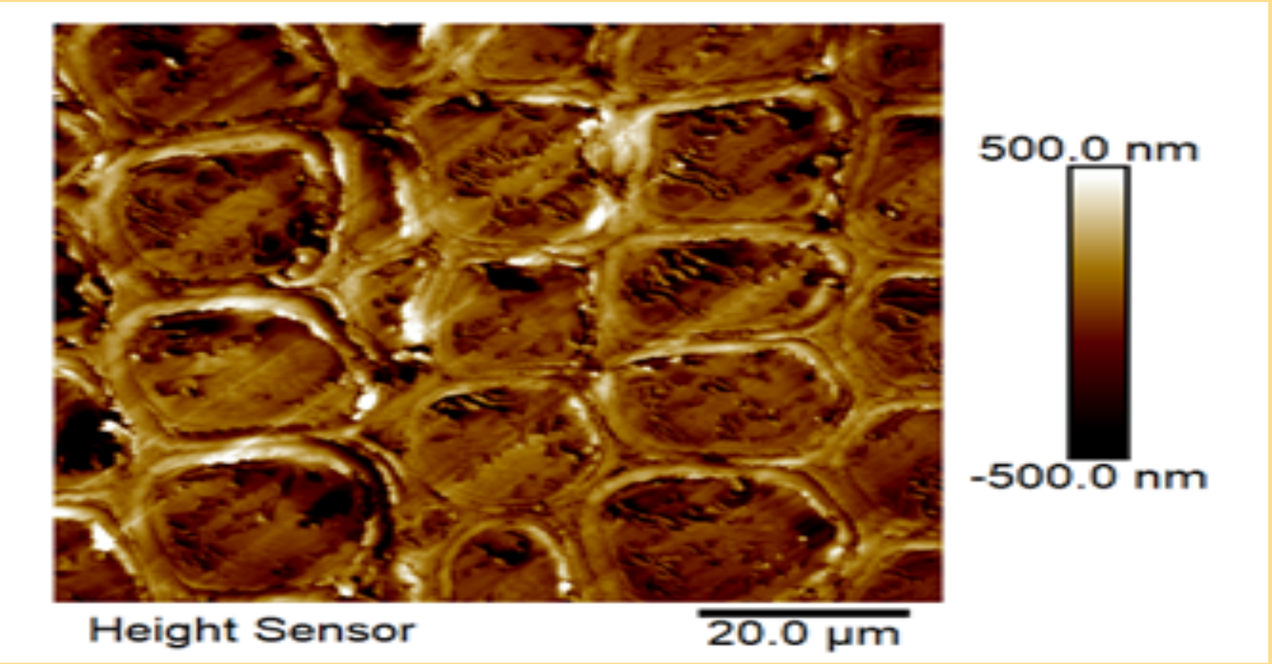


Surface energy
- Surface forces that correlate to wettability, flowability, cohesion

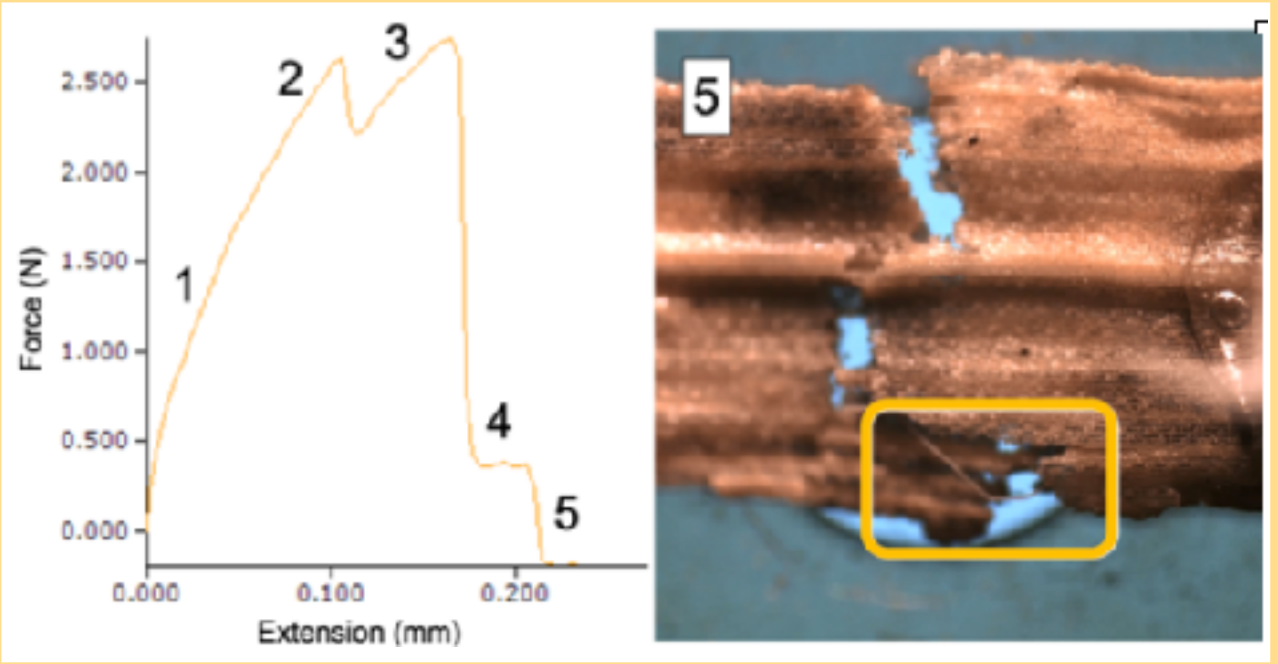


Microsurface texture
- Particle topology that impacts friction and interaction with surface water

Cell wall mechanical properties



Nanoindentation
- Elastic moduli, surface topology, deformation



In situ microscopy
- Structural integrity of biomass at the tissue, cellular, and cell wall scales

Advanced Chemical and Physical Characterization

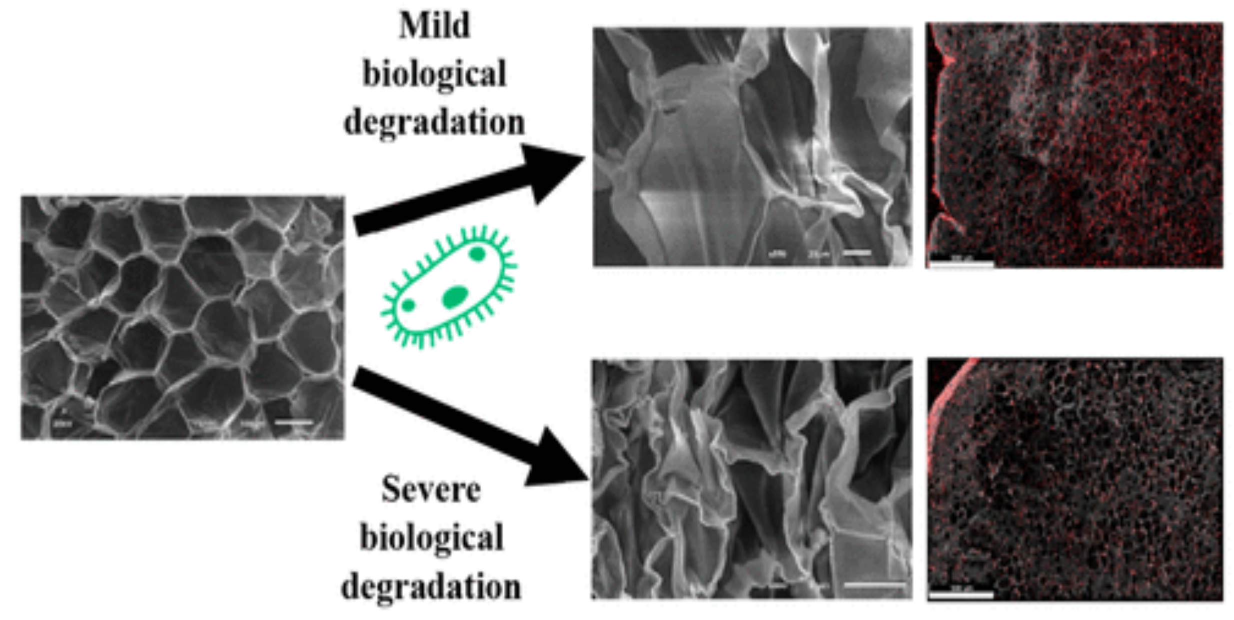
Cell wall polymer localization

Organosolv
Lignin Removal

Stimulated Raman scattering (SRS) microscopy
- Label-free, chemical imaging to localize lignin, xylan, and cellulose

Fluorescence lifetime and photon statistics
- Aggregation and modification of lignin

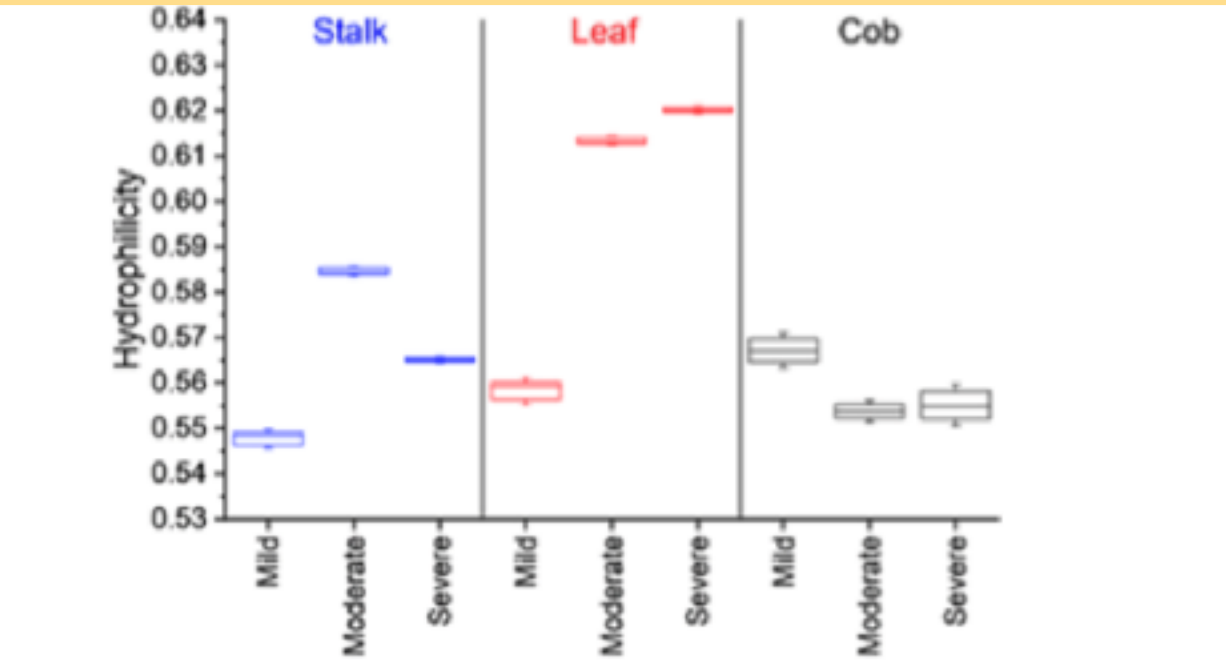
Cell wall inorganic localization



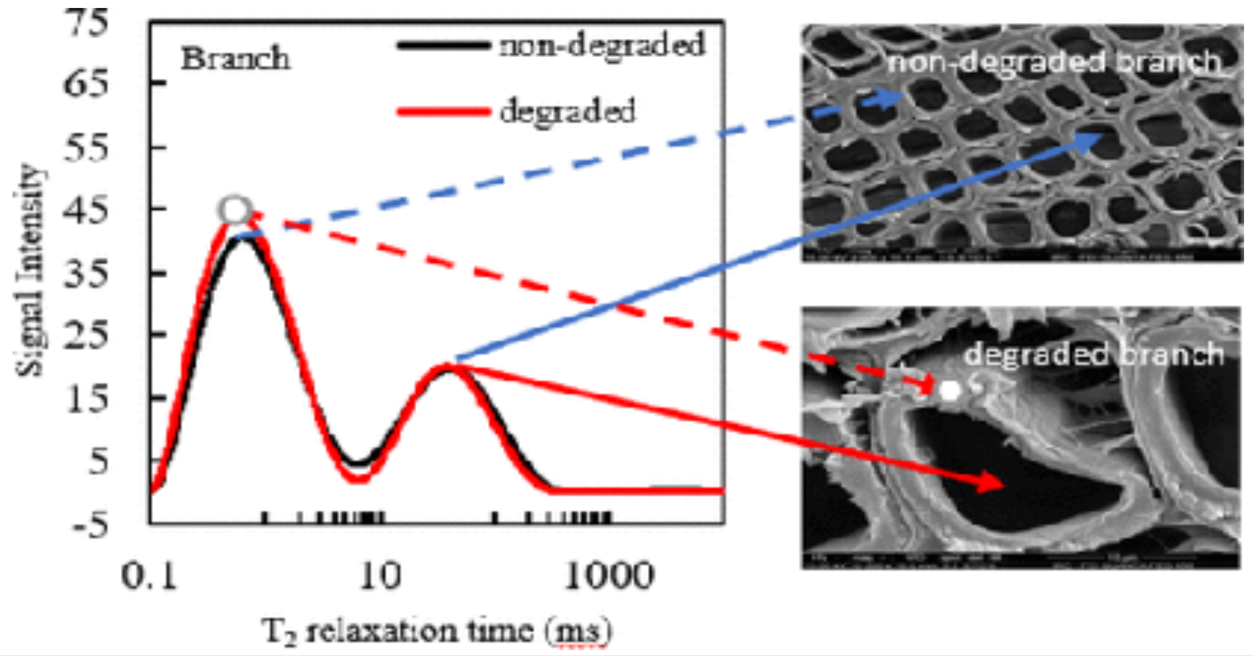
Scanning electron microscopy and energy-dispersive X-ray spectroscopy (SEM-EDS)
- Inorganic species localization within tissue and cell wall structure

X-ray fluorescence
- Determine identity and distribution of inorganic species

Particle/ water interactions



Hydrophilicity profile
- The ability to absorb or adsorb and retain water



Time-domain nuclear magnetic resonance (TD-NMR) relaxometry
- Water distribution and interaction with cell wall microstructure

Feedstock Variability Subtasks Target Other FCIC Tasks

Subtask 2.8: Cell wall architecture and integrity ➡ Task 5: Preprocessing

- Impacts on comminution and preprocessing.
- Experimental data for cell wall and tissue-scale attributes.

Subtask 2.9: Multiscale characterization of municipal solid waste (MSW) ➡ Task 6: High-temperature conversion

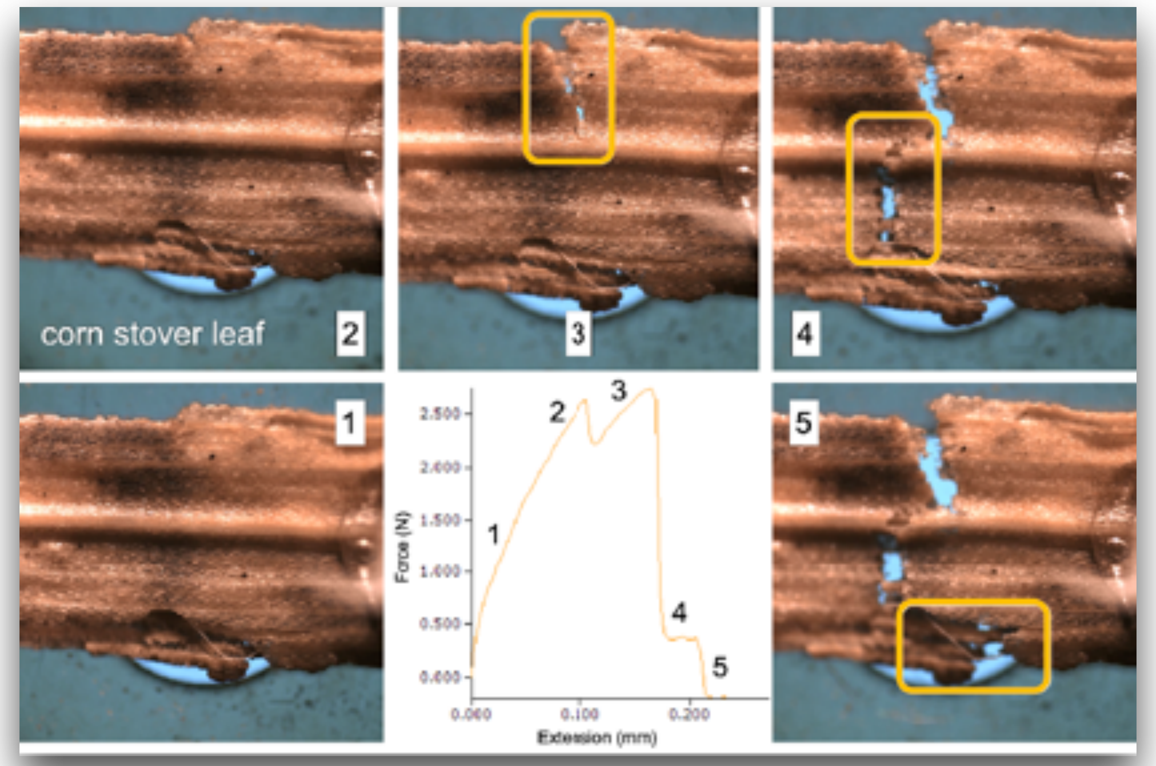
- Promote feedstock-flexible conversion.
- Similar and unique attributes between biomass and MSW.

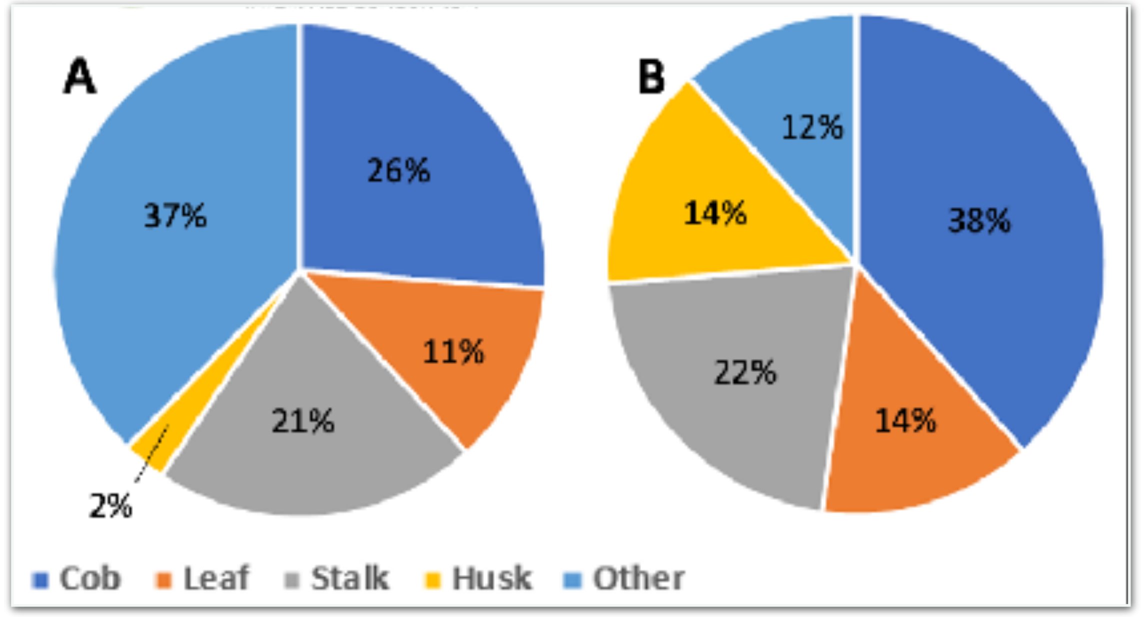
Subtask 2.10: Drought-stressed corn stover ➡ Task 7: Low-temperature conversion

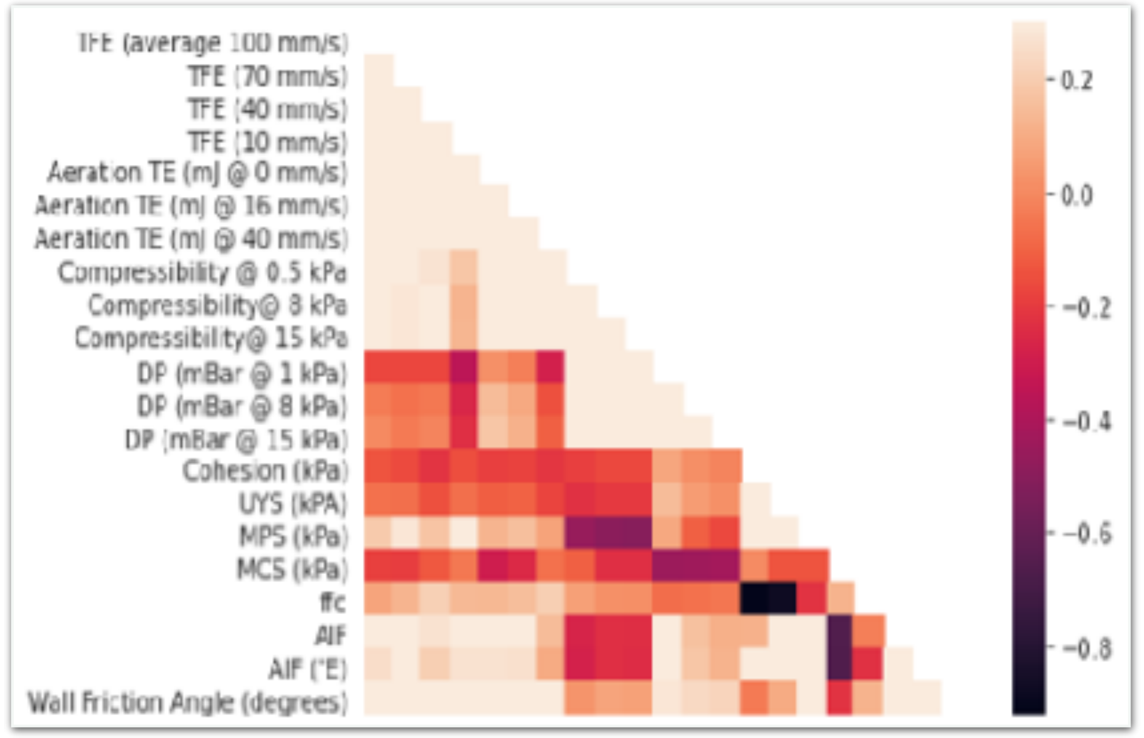
- Quantify multiscale compositional, structural, and thermophysical material attributes.
- Natural sources of variability and propagation through conversion.

Subtask 2.11: Data analytics and rapid characterization ➡ Tasks 4 and 8

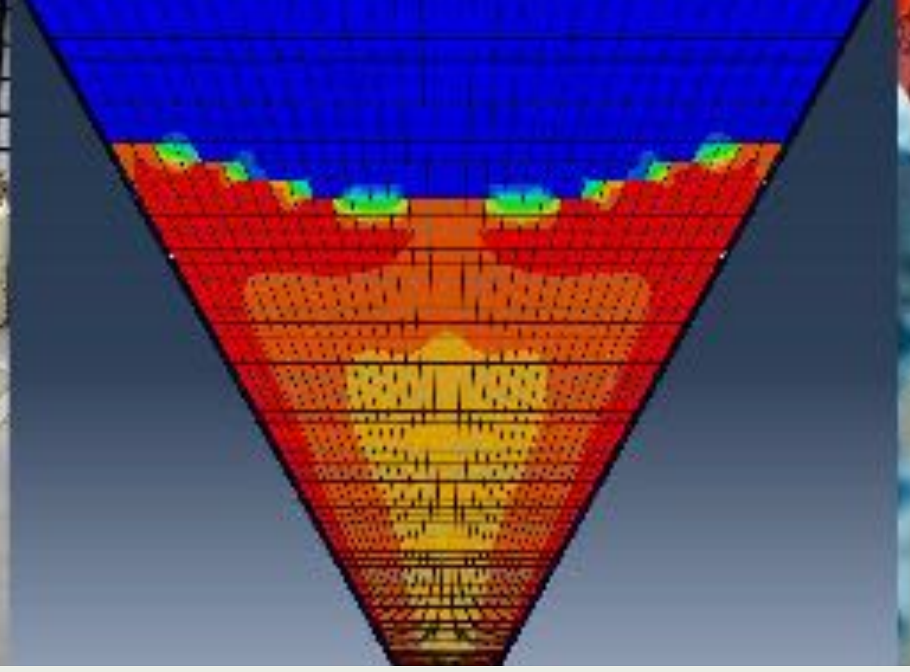
- Data analytics and machine learning to quantify the impacts of CMAs.
- Determine the distributions and limits of CMAs to ensure the desired quality.












2 – Progress and Outcomes

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Sources of feedstock variability

Growth

drought stress

Specific Impacts:

- ↑ xylan content
- ↓ inorganic content
- ↓ cell wall thickness
- ⇅ convertibility

Variability Source:

- anatomical fraction ratios
- depends on range of drought
- depends on range of harvest

Harvest

cut height or tree age

Specific Impacts:

- ↓ corn stem content
- ↑ pine wood content
- ⇅ moisture distribution
- ⇅ fracture patterns

Variability Source:

- anatomical fraction ratios
- extrinsic inorganic content

Storage

biological degradation

Specific Impacts:

- ↓ xylan content
- ↑ surface roughness
- ⇅ surface energy
- ↑ brittleness

Variability Source:

- leaves & husks more impacted
- bottom bales, more degraded
- bale cores, more degraded

Drought-Impacted Corn Stover

Growth

Knowledge

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Drought stress as a source of variability in corn stover feedstock attributes

Knowledge Gap

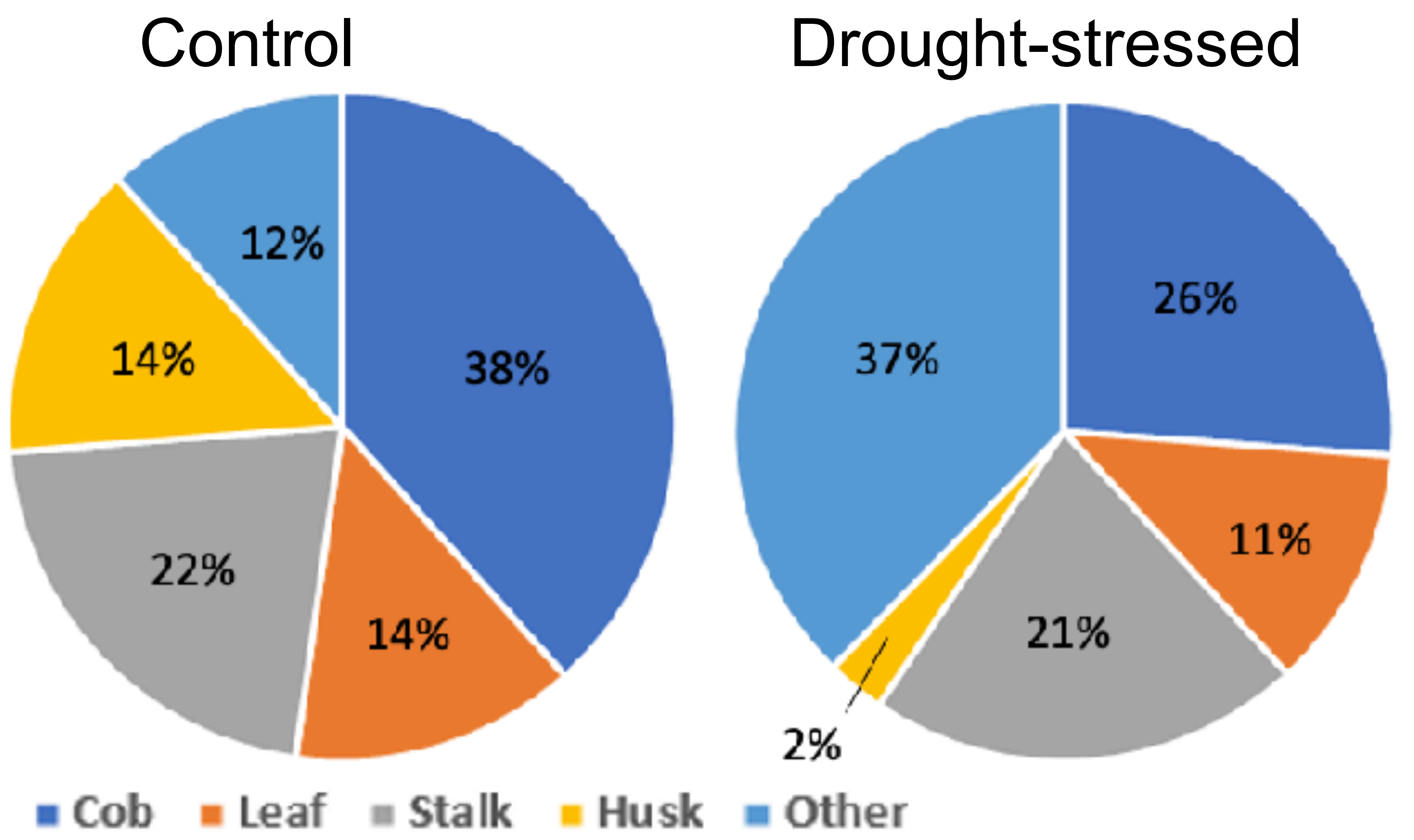
- How do growth conditions, including drought, contribute to feedstock variability?

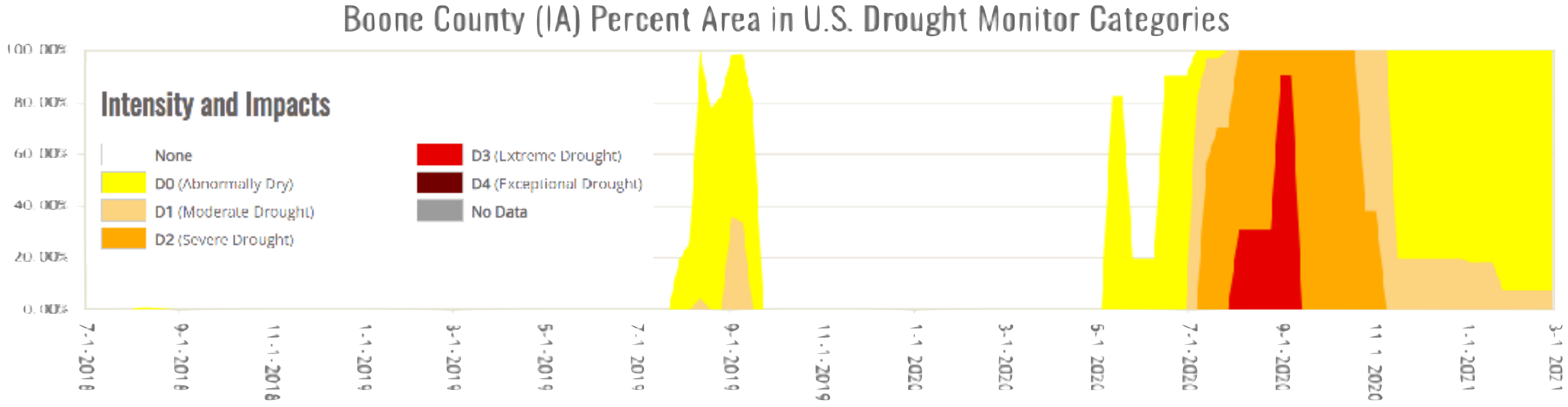
Achievement

- 2019 control bales and 2020 drought-stressed bales were acquired and distributed for FCIC campaign.
- Tissue types, composition, surface properties, cell wall structure, and integrity characterized.

Relevance

- Multiscale characterizations quantify variation in the corn stover's compositional, structural, and thermophysical attributes to understand the impact of drought on preprocessing, pretreatment, and conversion.





19% decrease in grain yield, 23% decrease in stover yield in 2020 (drought)

Attributes of Drought-Impacted Stover

Growth

Knowledge

Drought-impacted corn stover attributes

Knowledge Gap

- How does drought impact biomass quality and convertibility?

Achievement

- Drought conditions impact the distribution of nutrients and carbohydrates among anatomical fractions; leaves contain higher ash, extractives, and lignin but lower carbohydrates.
- Measured glucose and xylose yields from enzymatic hydrolysis of untreated and dilute acid-pretreated corn stover fractions for drought-stressed and control biomass.

Relevance

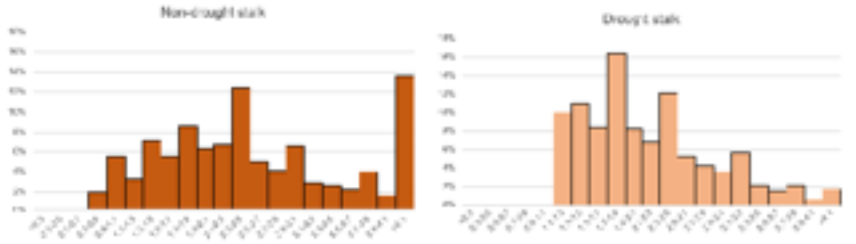
- Drought conditions impact the sugar yields of corn stover, and the impact varies among distinct anatomical fractions and pretreatment technologies.

Chemical attributes

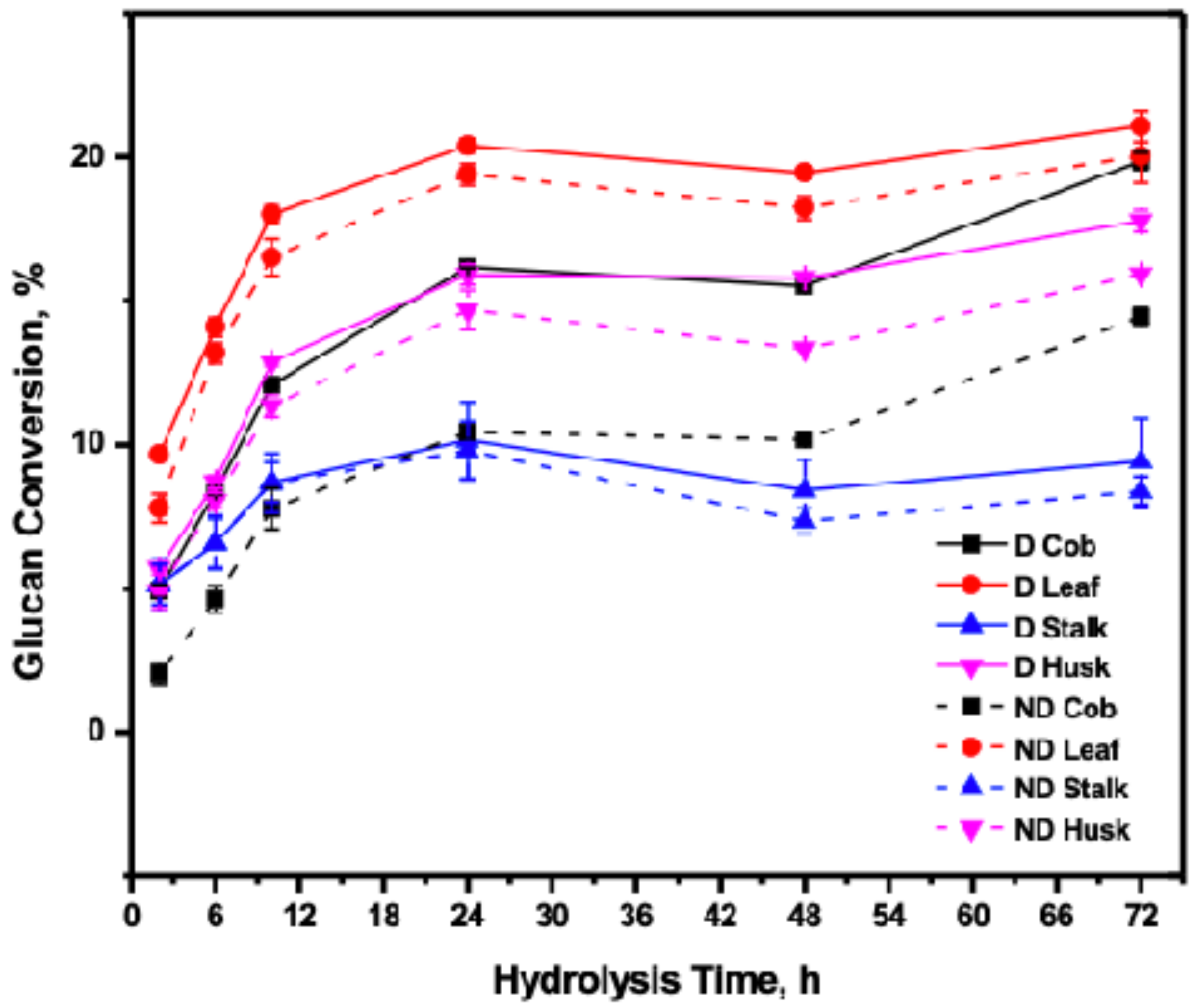
- Drought-stressed ↑ xylan and arabinan
- Drought-stressed ↑ acetate content
- Drought-stressed ↓ total ash content

Physical attributes

- Drought-stressed stover has **thinner** cell walls

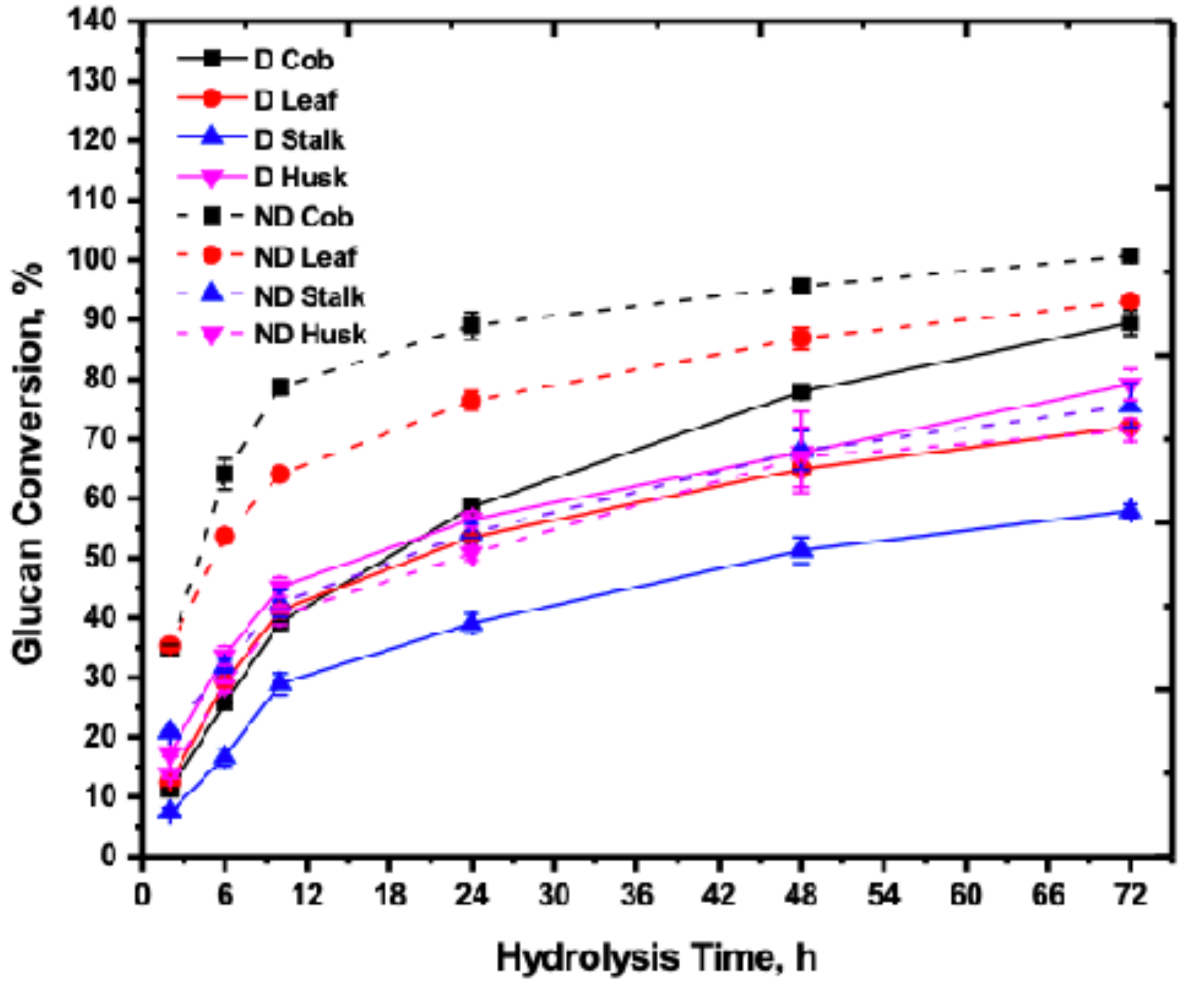


Untreated corn stover fractions



- Differences among anatomical fractions dominate glucan release
- leaves > husks > cobs > stalks
- non-drought > drought

Dilute acid pretreated corn stover fractions



- Differences in glucan release lessen after pretreatment
- cobs > leaves > husks > stalks
- non-drought > drought

TD-NMR Relaxometry Reveals Water Distribution in Anatomical Fractions

Harvest

Knowledge

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Understanding cell wall architecture that influences diffusion, accessibility, rheology, and recalcitrance

Knowledge Gap

- How do water status, distribution, and interactions influence chemical and physical changes in biomass?

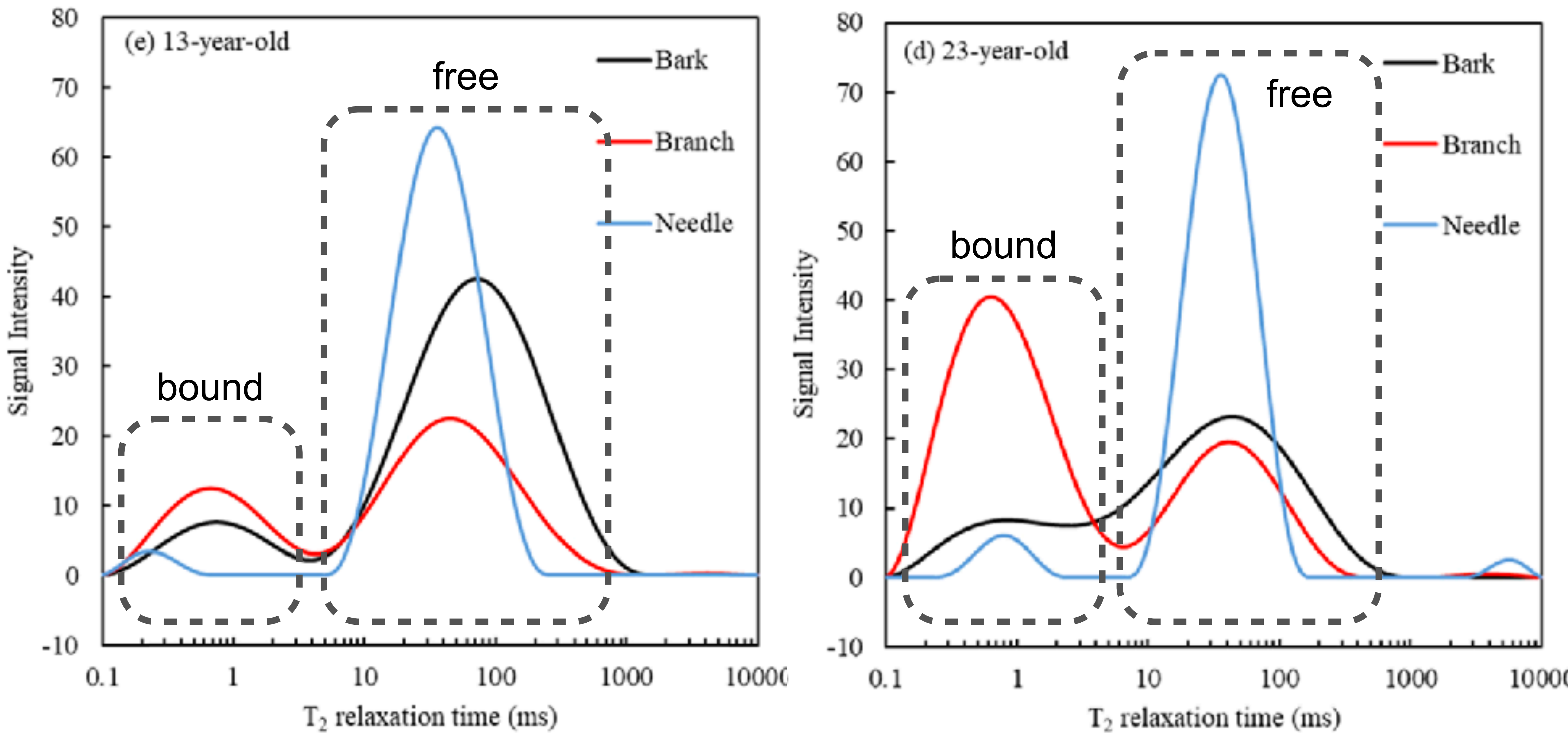
Achievement

- Low-field NMR was applied to understand the influence of local environments in porous materials and elucidate water interactions with biomass.
- The method can be used to monitor water status and distribution in anatomical fractions of corn stover and pine residues.

Relevance

- Provides insights to understand and manage feedstock variability, as well as informing harvest and storage practices.

Water distributions in pine tissues from 13- and 23-year-old trees



Ling Ding, Josephine N. Gruber, Allison E. Ray, Bryon S. Donohoe, and Chenlin Li, *ACS Sustainable Chemistry & Engineering* 2021 9 (47), 15884–15896, DOI: 10.1021/acssuschemeng.1c05606

Cell Wall Architecture and Structural Integrity

Variability in cell wall architecture and structural integrity leads to differences in comminution

Knowledge Gap

- What biomass attributes contribute to forming high-aspect-ratio particles and fines during preprocessing?

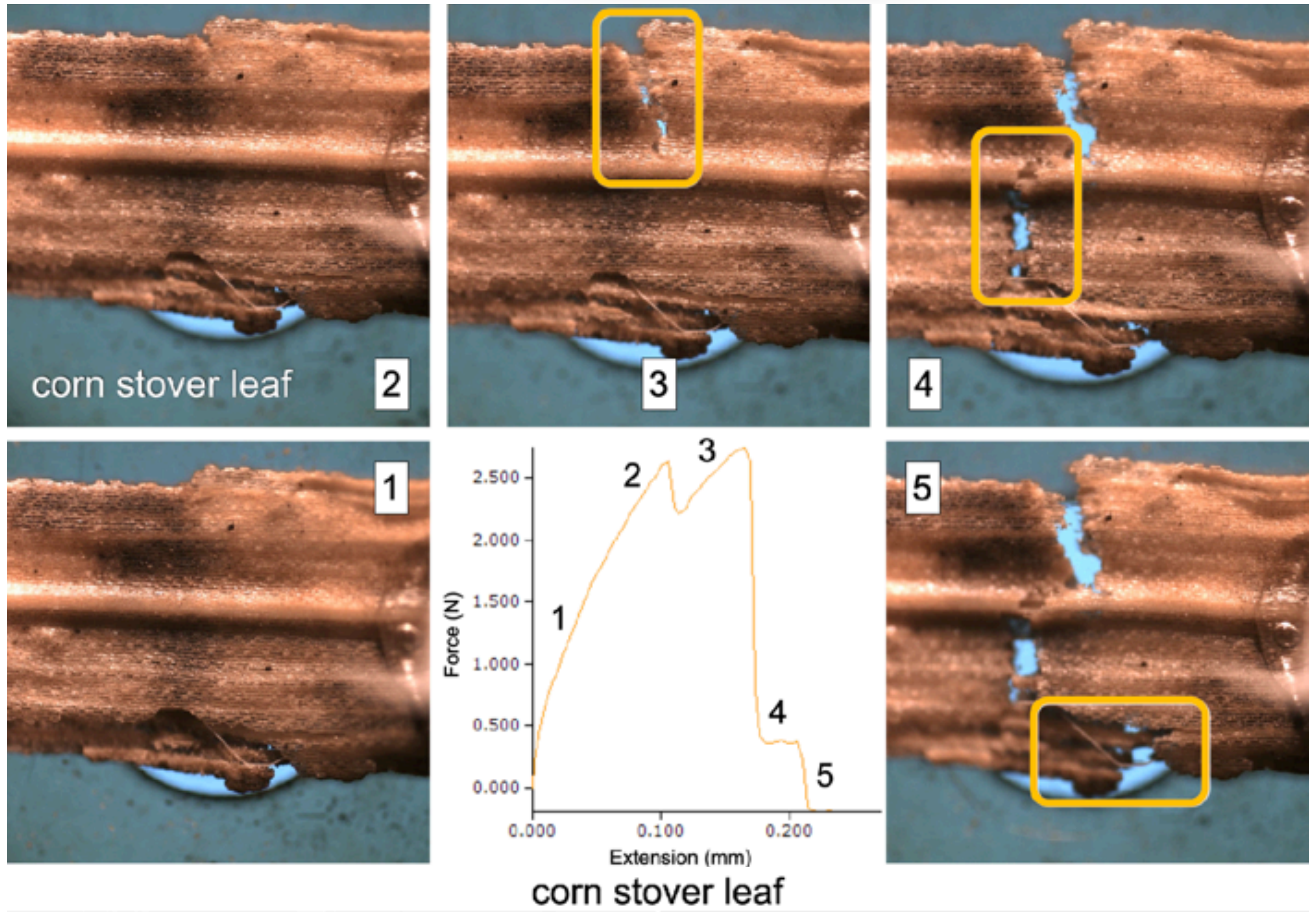
Achievement

- Developed methods to interrogate the structural integrity of biomass particles at the tissue, cellular, and cell wall scales.
- Tissues with weak cell-to-cell adhesion will tend to fracture between cell walls. Conversely, tissues with strong cell-to-cell adhesions will have an equal mix of fractionation between and through cell walls.

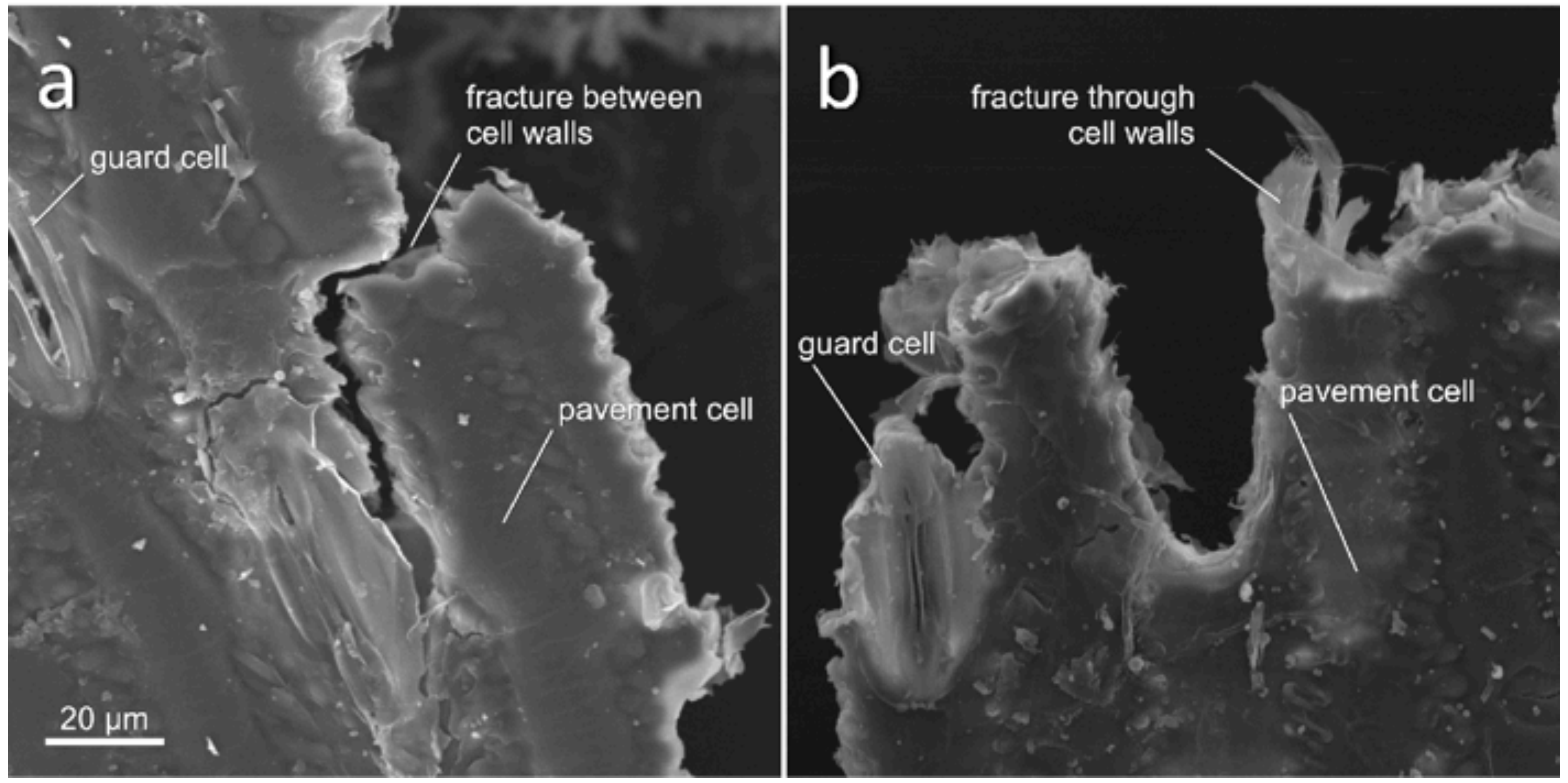
Relevance

- These findings suggest concepts for genetic or breeding targets to improve biomass attributes for bioconversion.

Optical micrograph still frames from a tensile strength testing experiment video



SEM micrographs of fracture patterns between and through cell walls can be distinguished



C. Benedict et al. Manuscript in preparation

Biologically Degraded Corn Stover Exhibits Changes in Surface Properties

Storage

Knowledge

Elucidating the effects of degradation on surface area and surface energy of corn stover

Knowledge Gap

- How does biological heating influence the surface properties of bulk and corn stover fractions?

Achievement

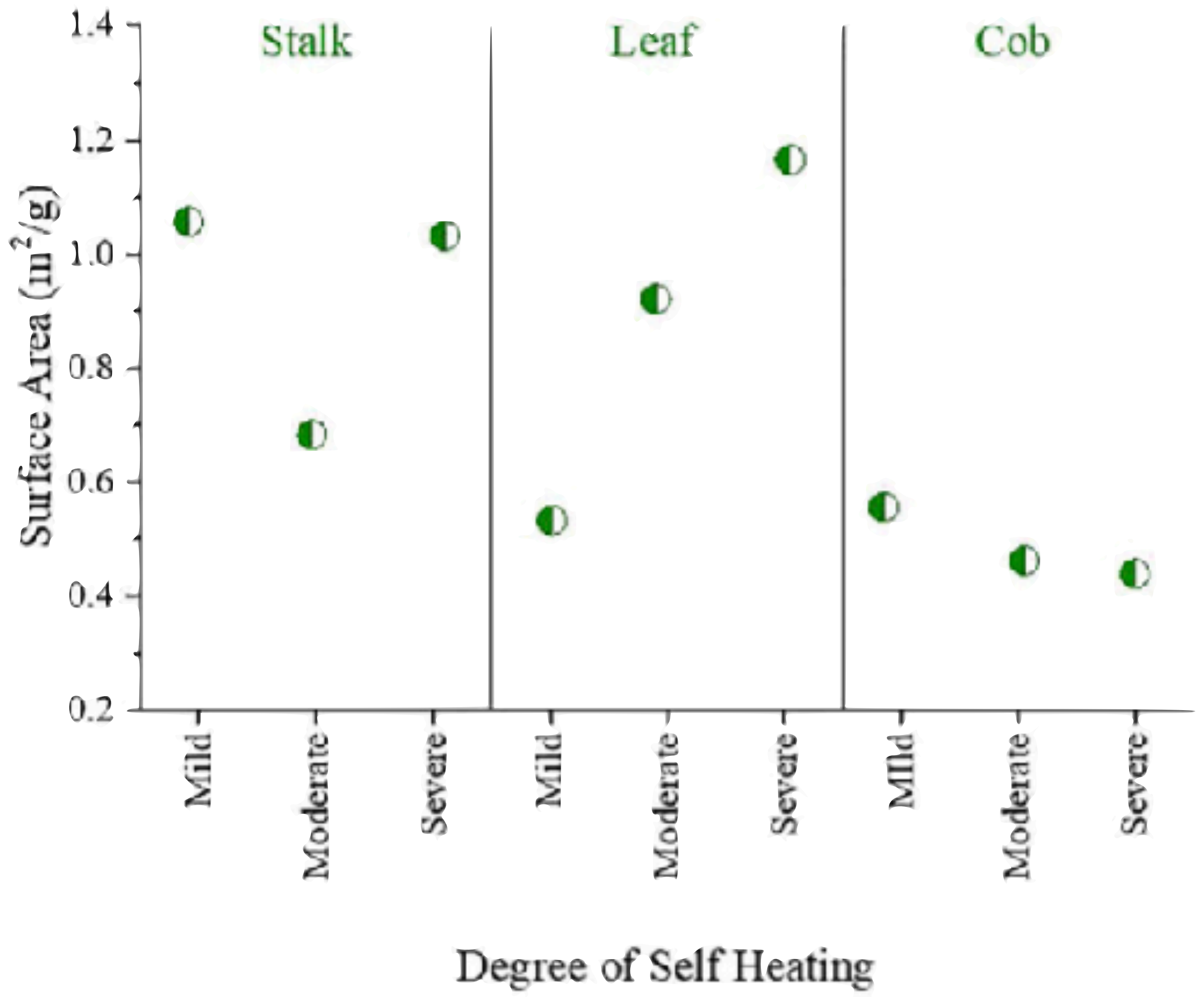
- A comprehensive study using inverse gas chromatography and nitrogen physisorption was carried out to discern the effects of biological heating on surface attributes.
- Anatomical fractions exhibited varying changes in their wettability, surface energy, and surface area.

Relevance

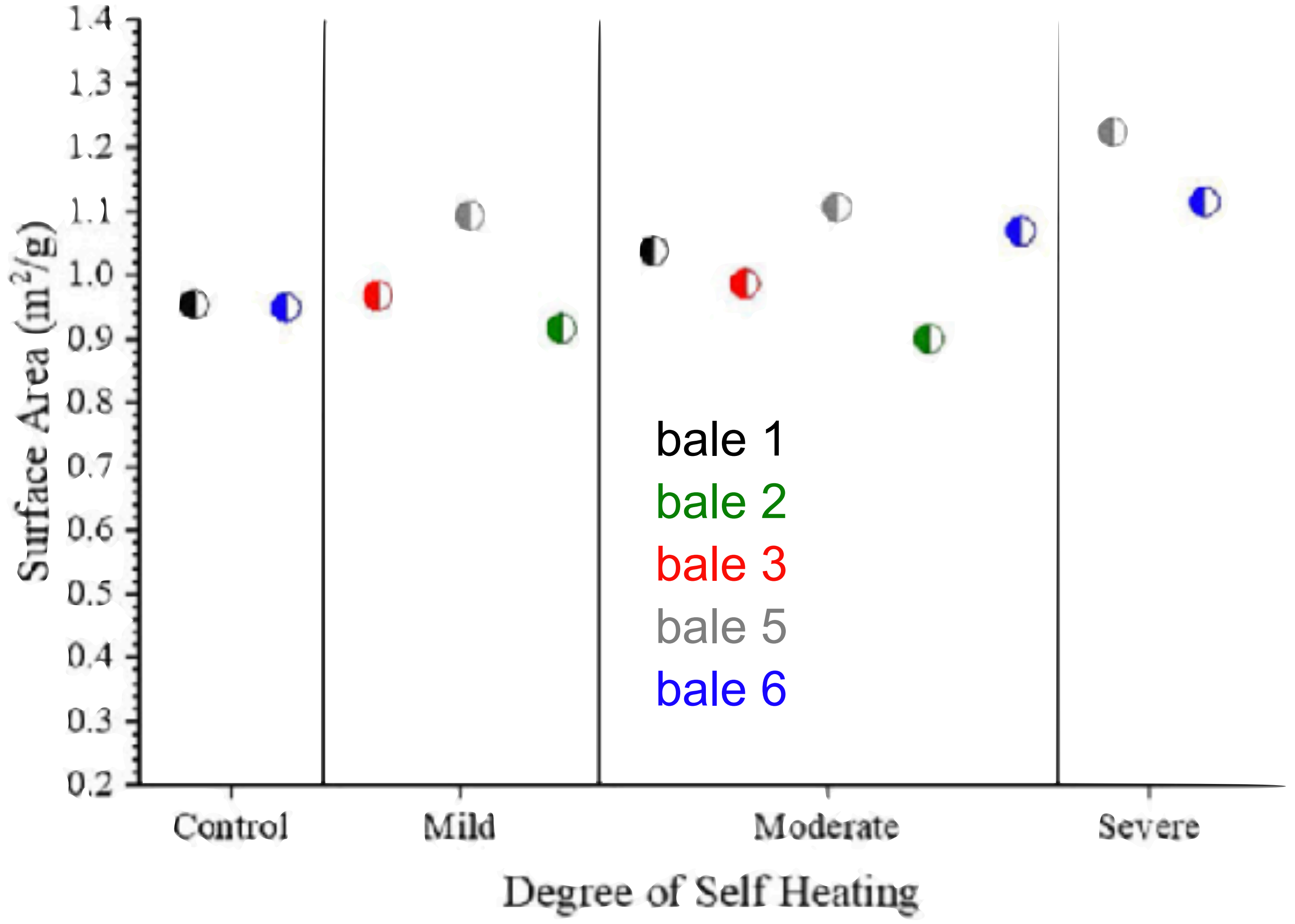
- Knowledge of the range of impacts of biological degradation during storage.

Corn stover bale with a visible gradient of degradation

Anatomical fractions



Stover bales



Juan H. Leal, Eric J. Meierdiercks, Ricardo Navar, Cameron M. Moore, Allison E. Ray, and Troy A. Semelsberger, *Front. Energy Res.*, 14 July 2022. https://doi.org/10.3389/fenrg.2022.868019

Microscale Mechanistic Insights into Macroscale Mechanical Properties

Storage

Knowledge

Changes in the lignin network conformation underlie the brittleness of degraded biomass

Knowledge Gap

- Does biological degradation during storage impact lignin?

Achievement

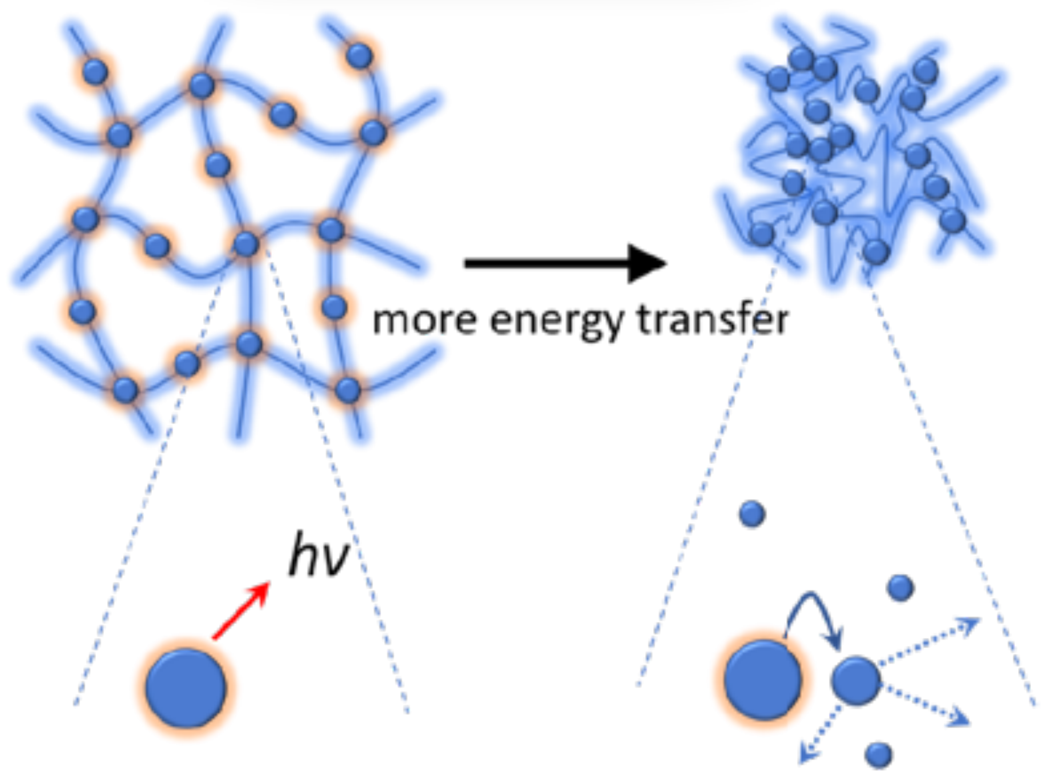
- Shortened fluorescence lifetime, reduced polarization modulation depth, and reduced photon emitters correlate to biological heating severity, suggesting changes in lignin structure and environment.
- If lignin collapse is taking place, microfibrils will be restricted from rearrangement and result in a less elastic material.

Relevance

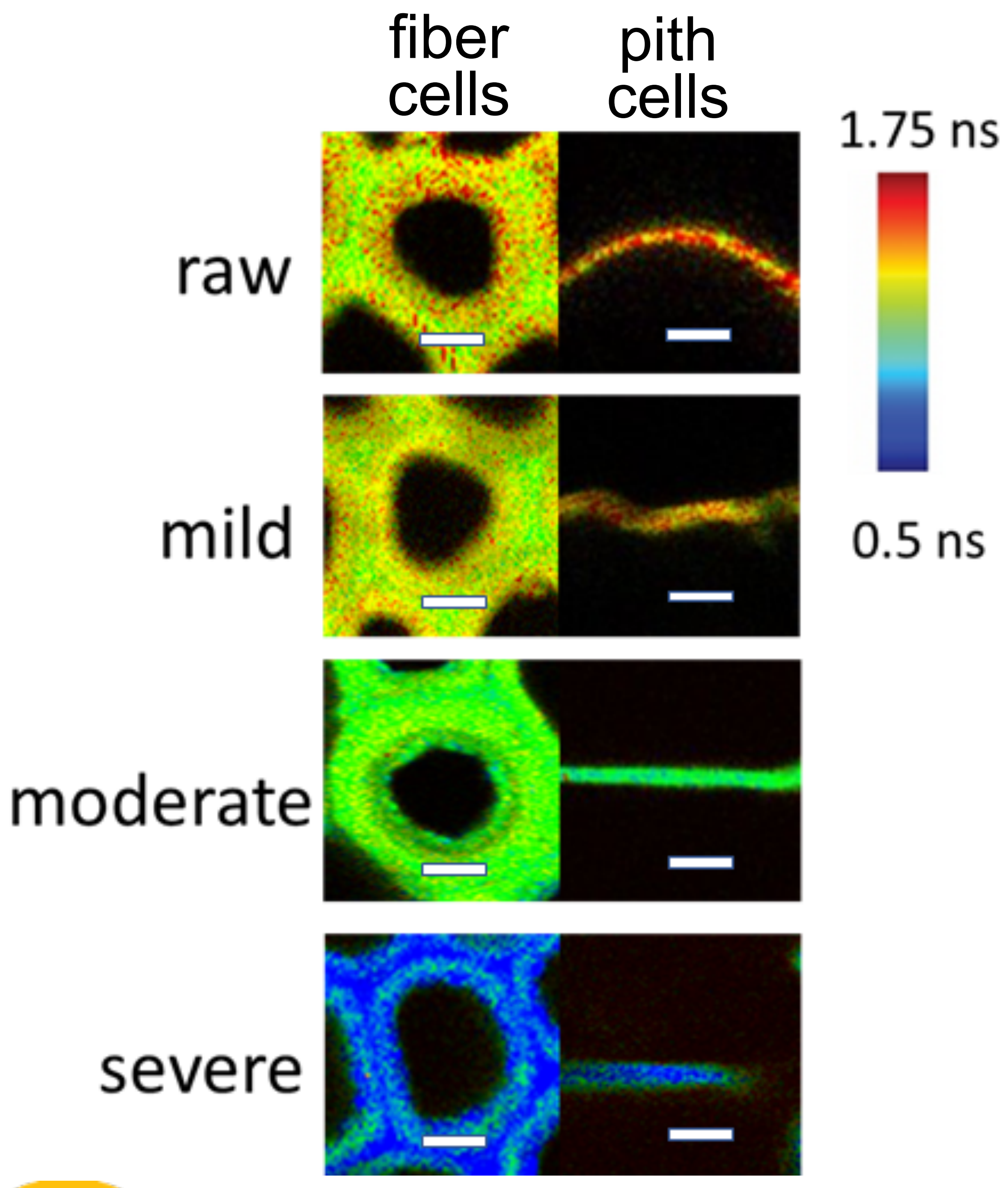
- Modifications to structure assembly in cell wall biopolymers have implications for mechanical and chemical processing.

Y. Zeng et al. Manuscript submitted, *PNAS*

Polymer network collapse leads to rapid energy transfer



Fluorescence lifetime imaging microscopy (FLIM) micrographs



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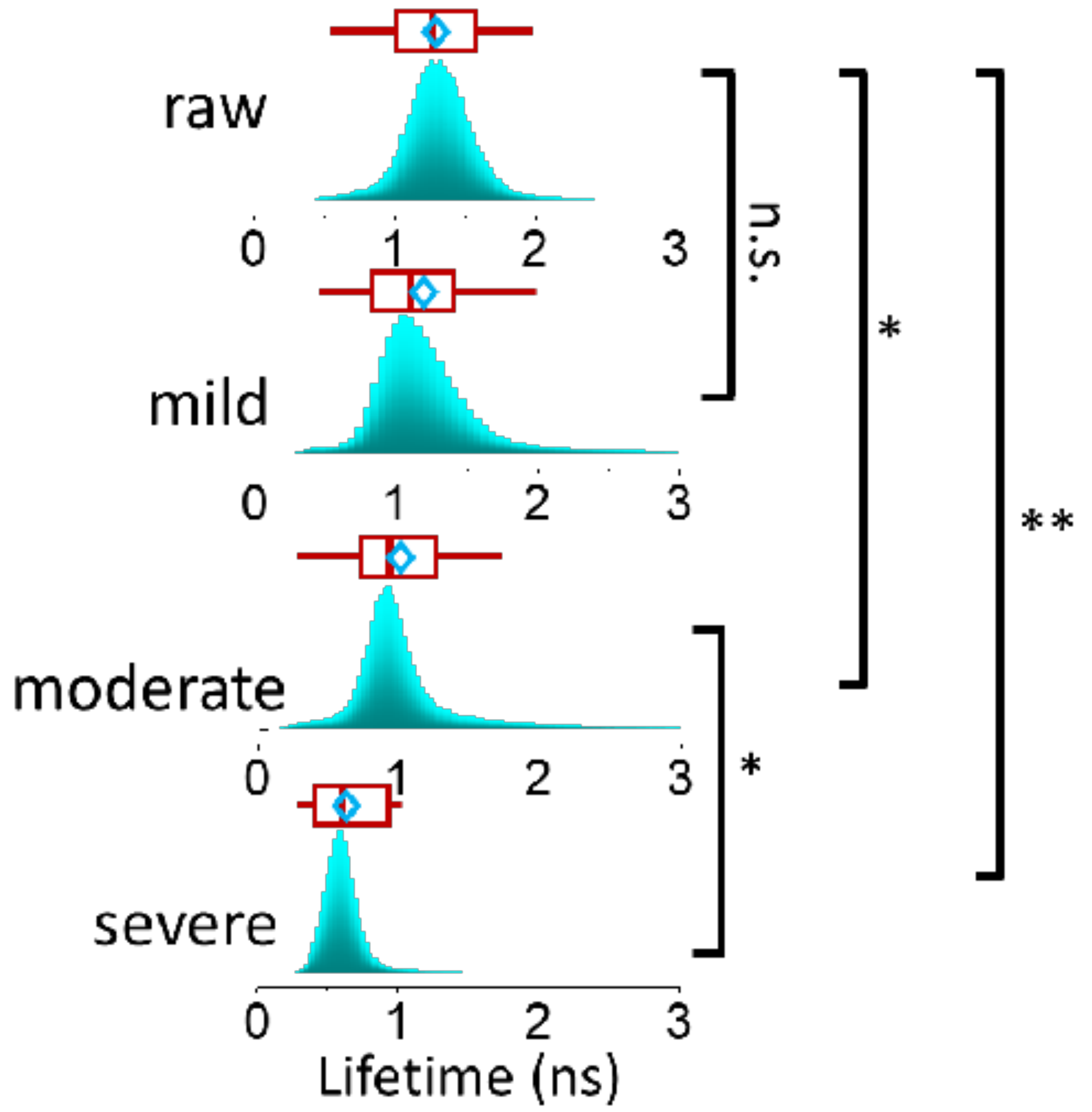
Fluorescence lifetime distributions



Establishing CMAs from Feedstock Attributes

Knowledge

Correlations among attributes and outputs

Knowledge Gap

- Are there relationships among attributes and processing outputs that can identify criticality?

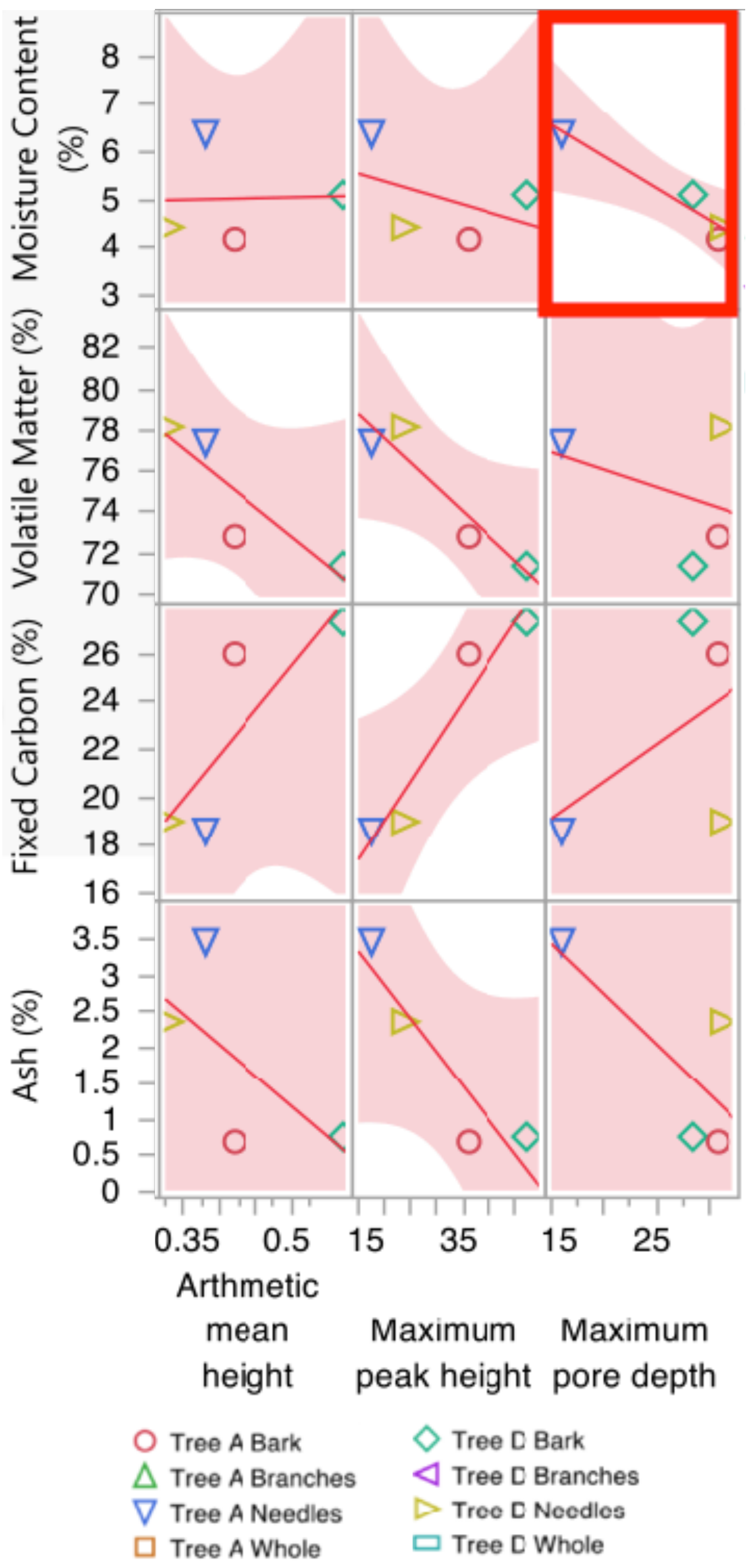
Achievement

- Established correlations among diverse attributes.
- Correlations among attributes and process outputs.

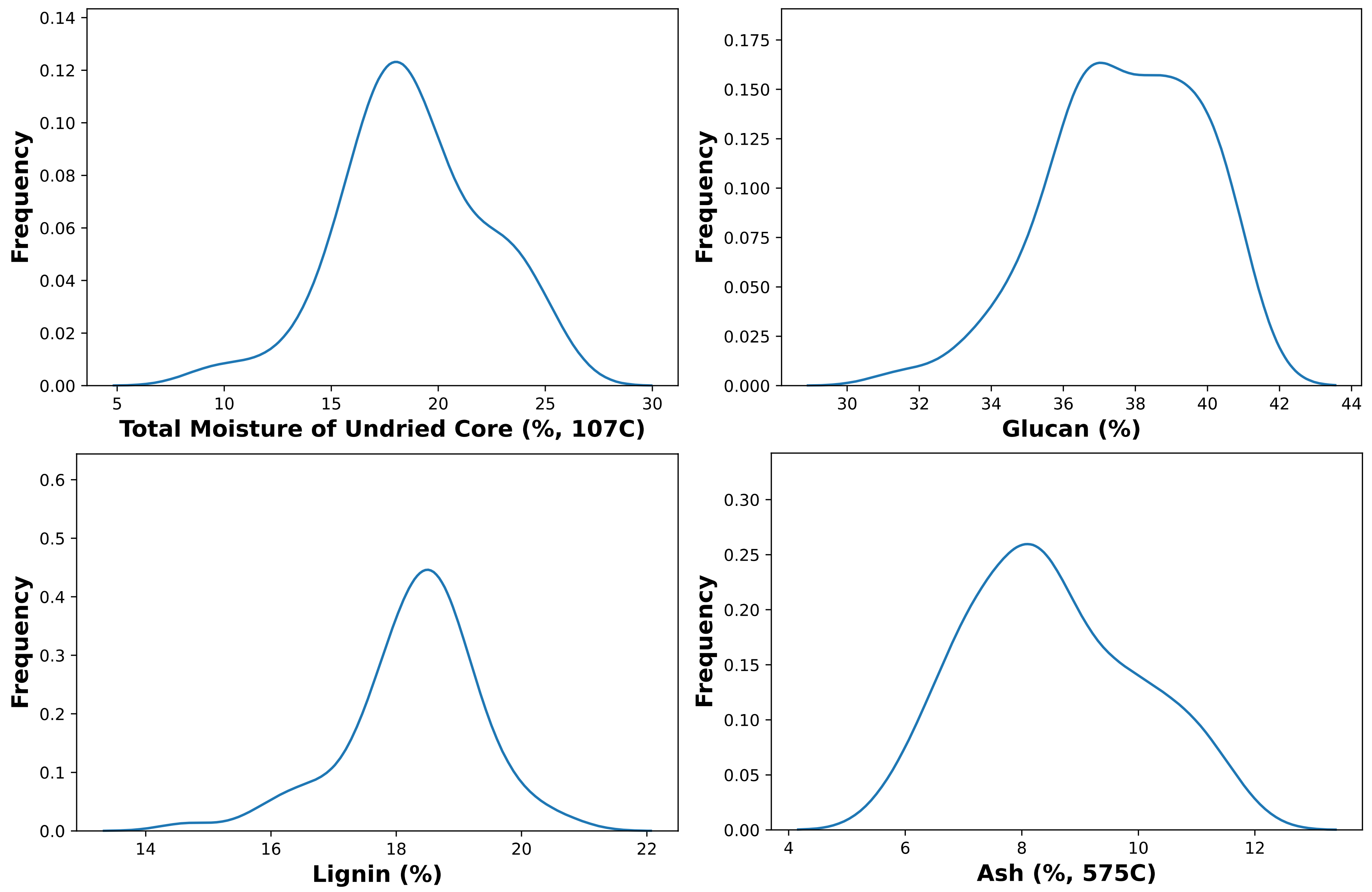
Relevance

- Correlations among material attributes narrow the number to measure.
- Statistical models of outputs as functions of feedstock attributes and process parameters to identify CMAs and CPPs.
- Analysis of distributions of CMAs and CPPs to establish limits on attributes to ensure desired quality.

Attribute Correlations



Generate Data Driven Models



$$Stage\ 1\ Grinding\ E = f\{feedstock\ measures\}$$

$$E = \frac{\%\,\Delta\, y}{\%\,\Delta\, x} > 1 \Rightarrow \text{CMAs}$$

Feature	Coefficient	Elasticity
Total Moisture (%, 107 °C)	0.06	0.07
Glucan (%)	0.44	0.91
Lignin (%)	2.53	2.53
Ash (%, 575 °C)	2.40	1.12

10% increase in lignin => 25% increase in stage 1 grinding energy

MSW Variability and Characterization

Knowledge

Applying variability characterization to new feedstocks to identify potential CMAs

Knowledge Gap

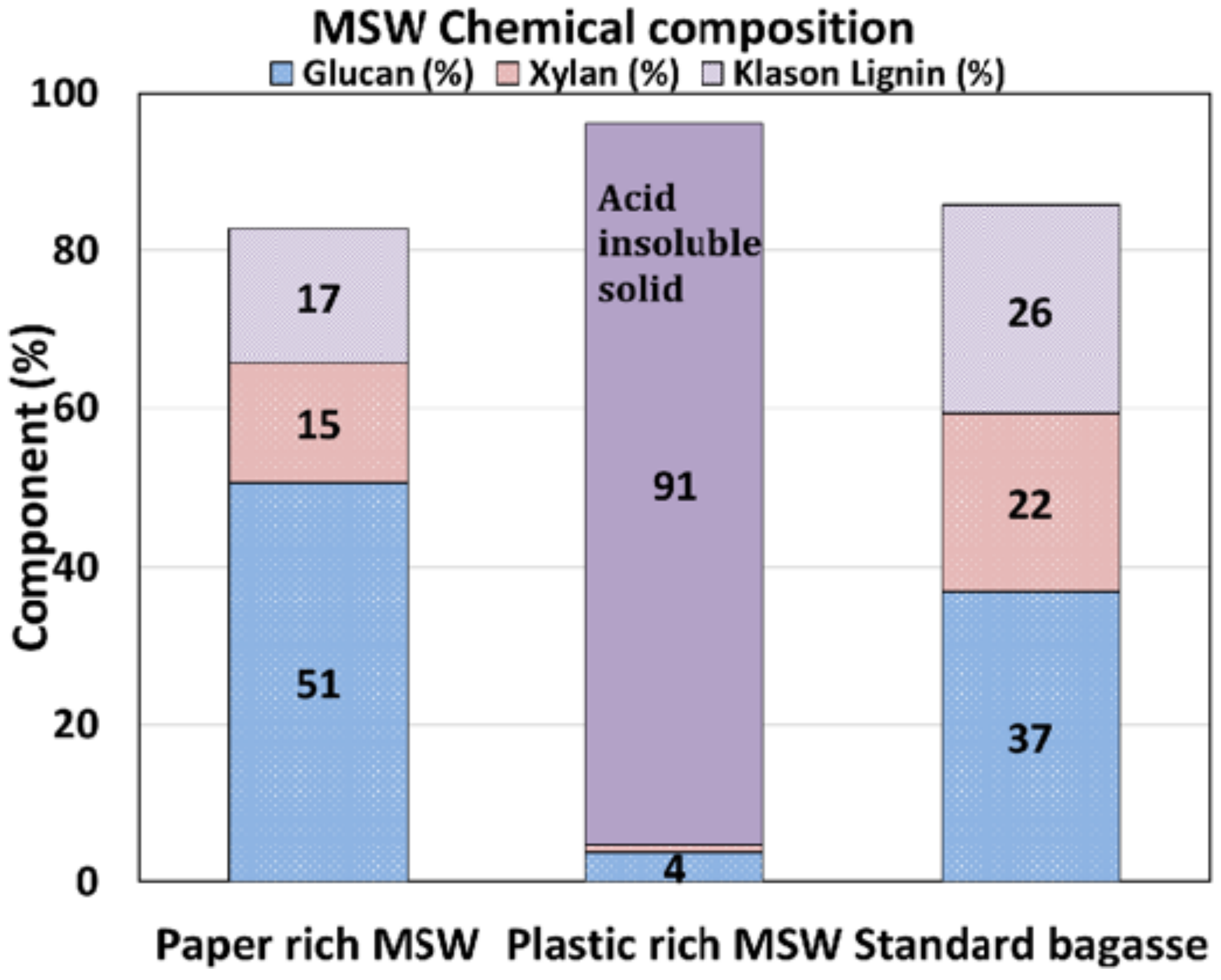
- What are the characterization needs for MSW streams, and how are those needs different from biomass feedstocks?

Achievement

- Particle size and shape analysis of >100K particles to enable 3D and heat transfer modeling
- Compositional analysis for conversion metrics and to indicate separation efficiency
- Thermogravimetric analysis (TGA) with different particle sizes to reveal variability

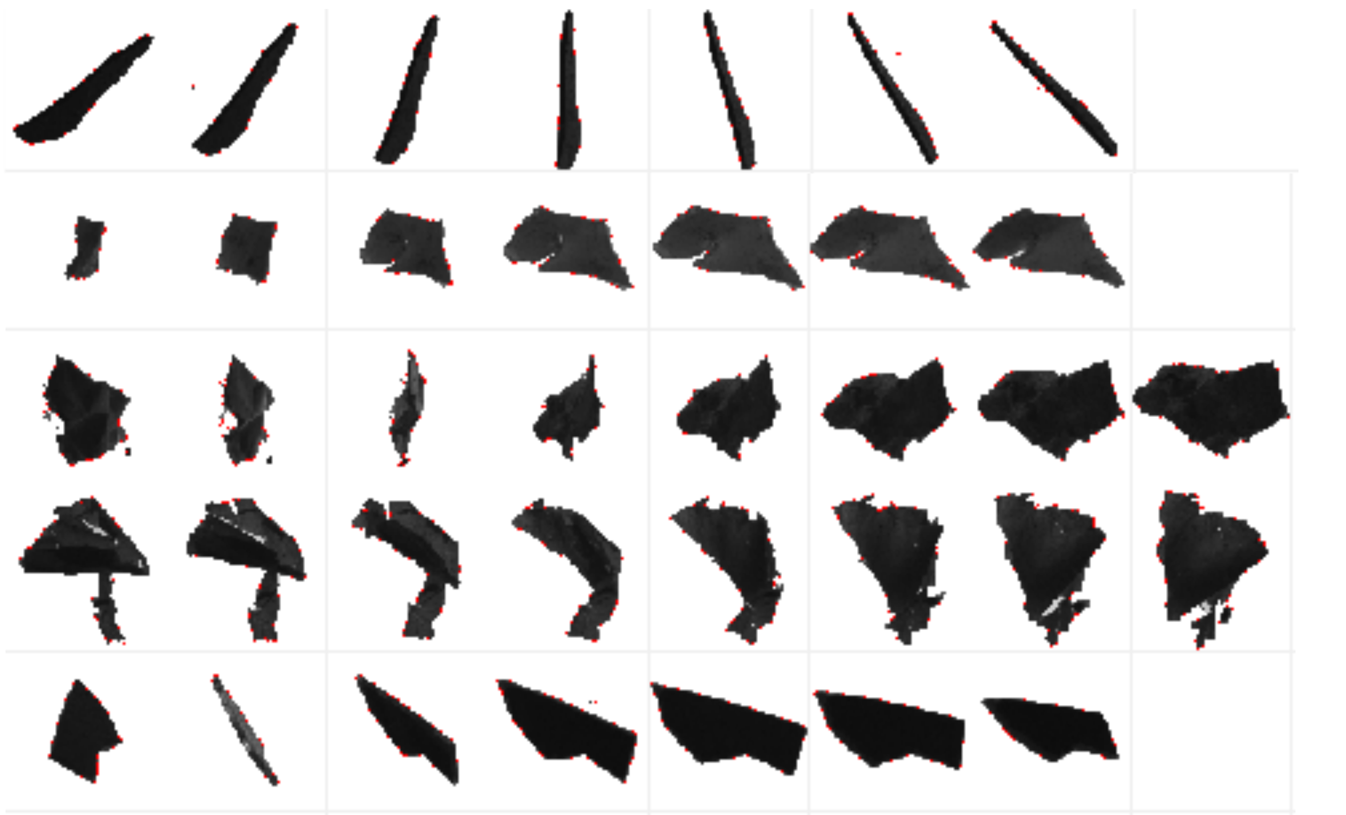
Relevance

- A significant step toward realizing an attribute-driven approach to feedstock quality analysis



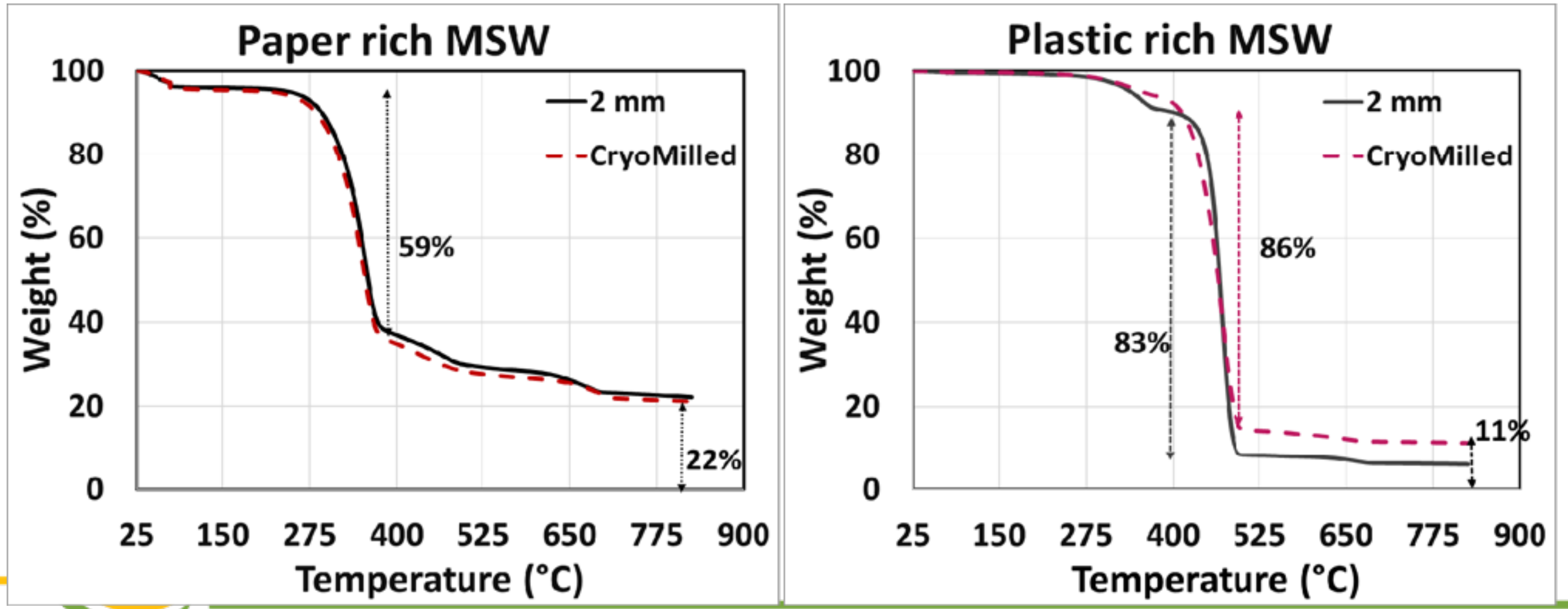
3D particle analysis of >100K 4 mm plastic crumbles

- mixed aspect ratios, low circularity, abundant fines

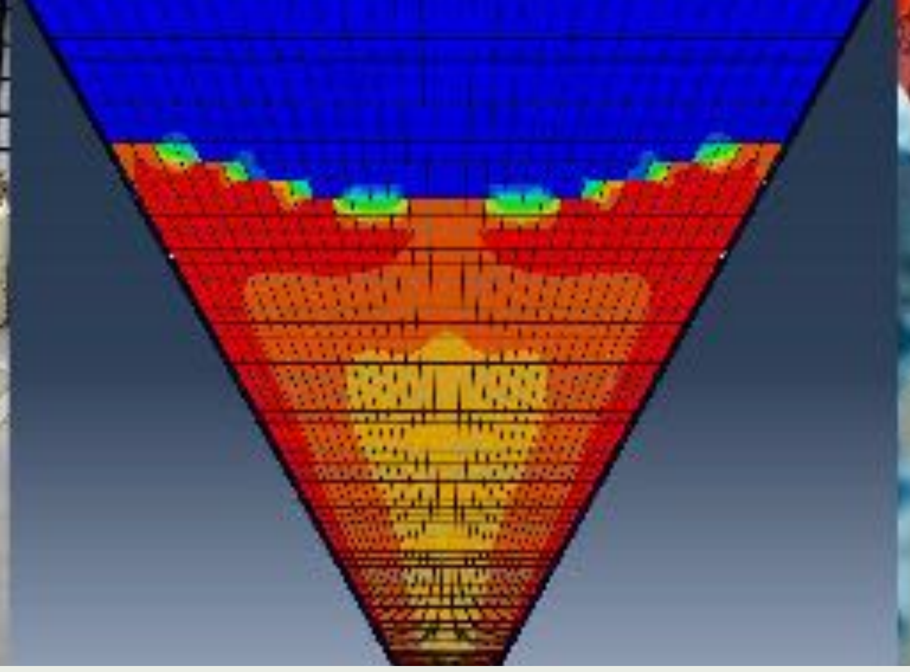


silhouette images of tumbling plastic particles used to derive size/shape parameters

Thermogravimetric analysis (TGA) of MSW streams








3 – Impact

Knowledge and Tools Dissemination

Impact:

- Providing **characterization tools and CMA variability data** that inform (1) storage and harvest best practices, (2) feedstock quality evaluation, and (3) selection configurations that manage variability.
- Feedstock suppliers, process designers, and equipment manufacturers can derive value from the fundamental knowledge that is critical to de-risking the industry.

Dissemination:

- **Publish** concise, readable, concept-driven, and data-supported publications in peer-reviewed scientific journals (7 papers FY21–FY23, 18 total).
- **Present** at scientific conferences and to other research groups and institutions to generate interest in our approach and results (6 talks FY21–FY23, 16 total).
- Publish summary heuristics and take-home lessons in **industry trade journals** (1 published, 3 concepts accepted).

https://biomassmagazine.com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Feedstock Variability: Causes, Consequences and Mitigation of Biological Degradation

Researchers from the U.S. DOE's Feedstock-Conversion Interface Consortium and Feedstock Logistics Program describe feedstock variability and why it matters for biorefinery operations.

By US DOE Feedstock-Conversion Interface Consortium | January 14, 2023

Feedstock variability is a general term for a broad range of biomass properties that can impact the efficient and continuous operation of a biorefinery. Corn stover, for example, can be considered waste or a coproduct feedstock of the corn grain industry. It usually costs less than dedicated energy crops.

However, even if corn stover is relatively cheap at the farm, collecting, transporting, and storing it creates logistical challenges that increase its cost as a feedstock. Importantly, how it is grown, harvested, and stored can impact quality. Take storage systems, for example. They are

Corn stover bales with obvious signs of biological degradation being processed for investigation at Idaho National Laboratory.
IMAGE: IDAHO NATIONAL LABORATORY

We've discussed a series of articles for upcoming issues of *Biomass Magazine*:

"Feedstock Variability: The impact of tree age at harvest on the suitability of forestry residues for conversion"

"Feedstock Variability: How can drought-stressed biomass best be incorporated into the biorefinery?"

"Feedstock Variability: Differences among biomass anatomical fractions and tissues at the core of feedstock variability"

Industrial Engagement

Alder Fuels: Characterizing contaminants and emulsions in bio-oil by microscopy.

Almond Board of California: Discussing characterization and valorization of almond shells.

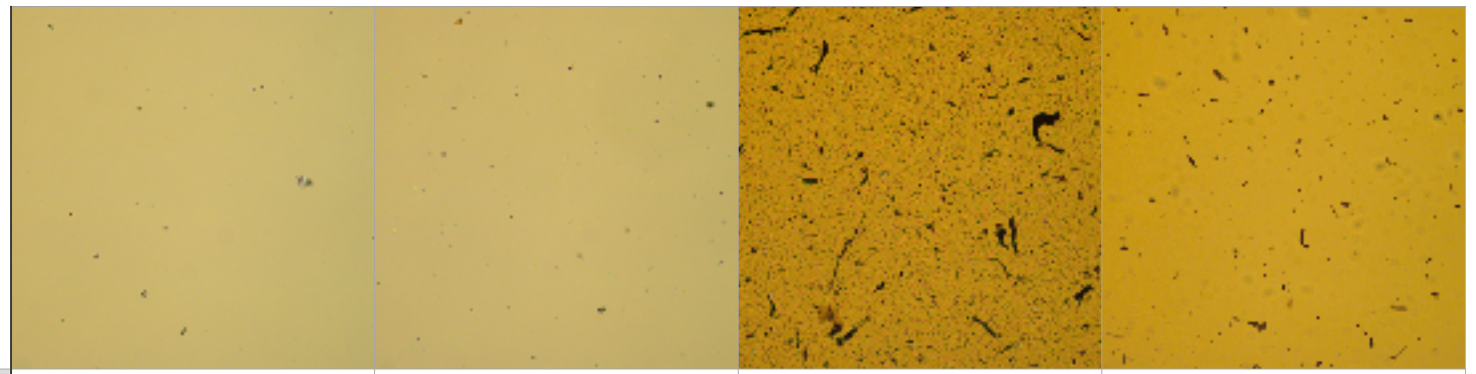
Amp Robotics: Discussing industry priorities for MSW characterization and conversion.

Molecular Vista: Applying photo-induced force microscopy (PFM) to corn stover.

Mycoworks: Discussing characterizing mycelium biomass after solid fermentation.

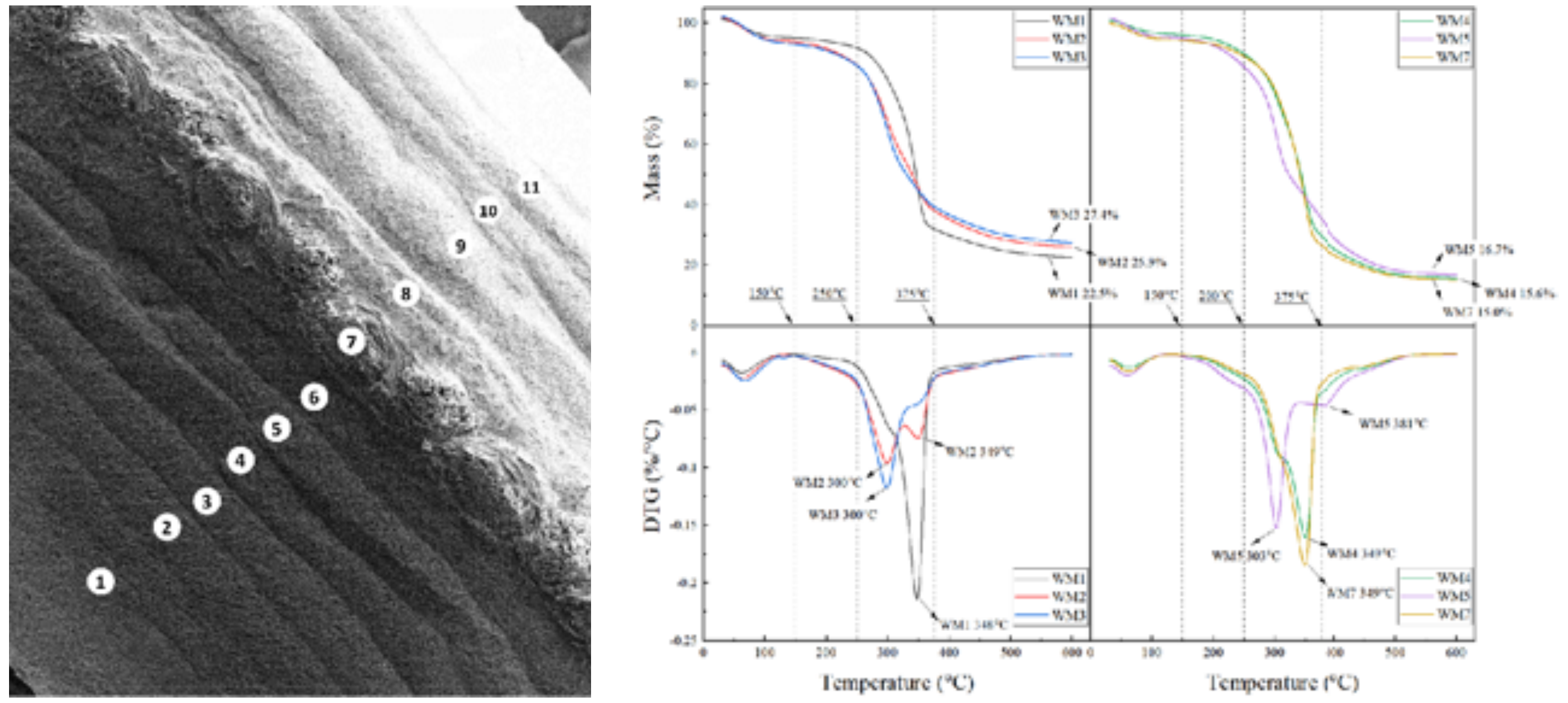
Quasar Energy Group: Developing multiscale characterization of MSW.

VERDE: Discussing producing nanocellulose using inexpensive biomass feedstocks.



Particle count	495	916	23,984	3,420
Average dia. [µm]	5.42	4.79	4.90	7.43

Bright-field micrographs and particle size analysis of bio-oil



SEM micrograph and TGA of fungal mycelium

ALDER FUELS AMP ROBOTICS™ molecular VISTA MYCO WORKS quasar energy group VERDE NANOMATERIALS

Summary

Technical Approach

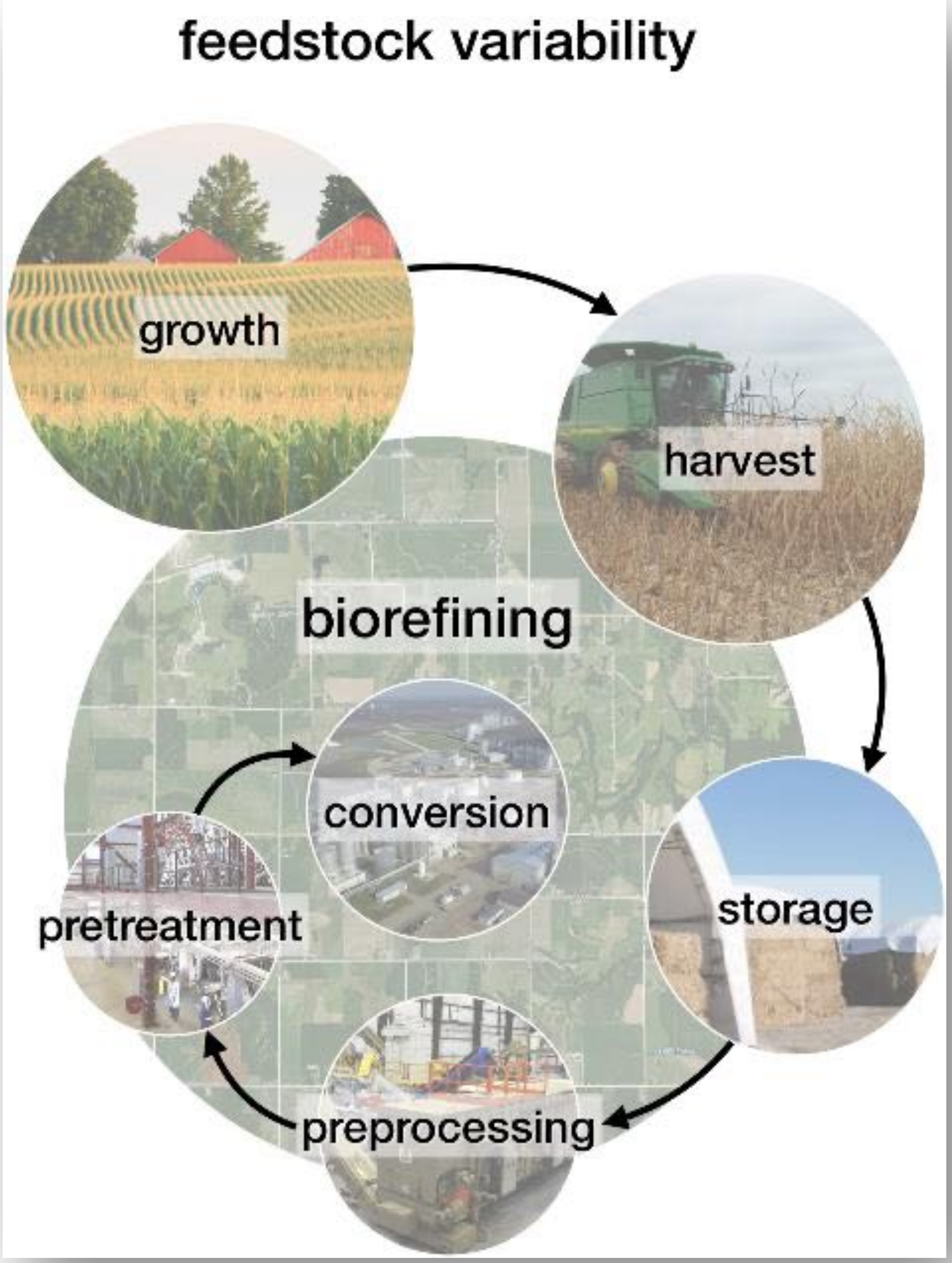
Multiscale characterization to identify and understand feedstock variability, focused on how the structural and physicochemical attributes of cell wall architecture and biomass tissues underlie flow behavior and mechanical and thermochemical deconstruction.

Impact

Providing characterization tools and CMA variability data that inform (1) storage and harvest best practices, (2) feedstock quality evaluation, and (3) selection of process configurations that manage variability

Achievements

Identified and disseminated knowledge about the importance and potential application of ~60 attributes of feedstock variability (narrowing down to ~6) that can be used to evaluate feedstock quality and mitigate biorefinery disruptions.



Quad Chart Overview

Timeline

- *Project start date: October 1, 2021*
- *Project end date: September 30, 2024*

	FY22 Costed	Total Award
DOE Funding	$1,230,000	$3,690,000

TRL at Project Start: N/A
TRL at Project End: N/A

Project Goal

To provide fundamental knowledge and tools that identify and quantify initial feedstock critical material attributes (CMAs) and inform strategies to manage the distribution and sources of feedstock variability.

End of Project Milestone

Provide the distributions, sources, and mitigation strategies for inherent feedstock CMAs that FCIC has shown to impact preprocessing and conversion of corn stover, pine residues, and MSW.

In collaboration with Tasks 3, 5, 6, and 7, quantify the impacts of the variability of inherent CMAs on preprocessing and conversion processes and identify sources, distributions, and mitigation strategies of CMAs for downstream processing of corn stover, forest residues, and MSW.

Funding Mechanism

2021 Lab Call – FCIC Merit Review

Additional Slides

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Responses to Previous Reviewers' Comments

- "The effort appears to be almost entirely focused on corn stover and wood chips. The reason for this choice could have been expanded either in this presentation or at a higher level." Task 2 has continued to understand the inherent and introduced variability of these two model feedstock resources, but our focus on the attributes themselves should translate to other feedstocks. We have also expanded to MSW.
- "The [material attributes] being developed are novel and increase the level of understanding of the impact of material variability. There is a need to determine the criticality of these attributes on the process parameters and determine if critical to industry." We continued to validate criticality using k-means clustering of measurements. We identified three critical material attributes (CMAs)—moisture, total ash, and extractives content—along with belt speed as a critical process parameter (CPP), which combined explain 67% of the variability in grinder energy consumption in the low-temperature conversion pathway.
- "There was no mitigation strategy discussed for the critical risk identified by the PI for 'translating fundamental understanding of... feedstock variability into knowledge and tools that can be easily transferred to industry.'" We agree that cross-review of the findings by the FCIC preprocessing and conversion groups and industry advisors is important to ensure industry relevance and real-world implementation strategy. We reoriented our subtasks to be more closely coordinated with the other FCIC tasks.

Publications, Patents, Presentations, Awards, and Commercialization

Publications

- L. Ding, J.N. Gruber, A.E. Ray, B.S. Donohoe, and C. Li, "Distribution of Bound and Free Water in Anatomical Fractions of Pine Residues and Corn Stover as a Function of Biological Degradation," *ACS Sustainable Chemistry & Engineering* 2021 9 (47), 15884–15896, https://doi.org/10.1021/acssuschemeng.1c05606
- Z. Cheng, D.W. Gao, F.M. Powers, R. Navar, J.H. Leal, O.O. Ajayi, and T.A. Semelsberger, "Effect of Moisture and Feedstock Variability on the Rheological Behavior of Corn Stover Particles," *Frontiers in Energy Research 2022* 10, 868050. https://doi.org/10.3389/fenrg.2022.868050
- L. Ding, A.N. Hoover, R.M. Emerson, K.-T. Lin, J.N. Gruber, B.S. Donohoe, J.L. Klinger, R.D. Colby, B.J. Thomas, W.A. Smith, and A.E. Ray, "Image Analysis for Rapid Assessment and Quality-Based Sorting of Corn Stover," *Front. Energy Res.* 2022 10, 837698, http://doi.org/10.3389\fenrg.2022.837698
- J.H. Leal, E.J. Meierdierks, R. Navar, C.M. Moore, A.E. Ray, and T.A. Semelsberger, "Impacts of biologically induced degradation on surface energy, wettability & cohesion of corn stover," *Frontiers in Energy Research/Bioenergy and Biofuels* 2022, https://doi.org/10.3389/fenrg.2022.868019
- A. E. Enrriques, S. Howard, R. Timsina, N. K. Khadka, A. N. Hoover, A. E. Ray, L. Ding, C. Onwumelu, S. Nordeng, L. Mainali, G. Uzer, and P. H. Davis, "Atomic Force Microscopy Cantilever-Based Nanoindentation: Mechanical Property Measurements at the Nanoscale in Air and Fluid," *J. Vis. Exp.* 2022 190, e64497, https://pubmed.ncbi.nlm.nih.gov/36533832/
- Ling Ding, Yingqian Lin, Kuan-Ting Lin, Kenneth L. Sale, Ning Sun, Bryon S. Donohoe, Allison E. Ray, and Chenlin Li, "Variability, Transport, and Impacts of Inorganic Species in Woody Biomass—A Review," submitted to *Renewable and Sustainable Energy Reviews*.
- B. Donohoe, W. Smith, L. Ding, and L. Wendt, "Feedstock Variability: Causes, Consequences and Mitigation of Biological Degradation," *Biomass Magazine*, Jan. 14, 2023, https://biomassmagazine.com

Publications, Patents, Presentations, Awards, and Commercialization

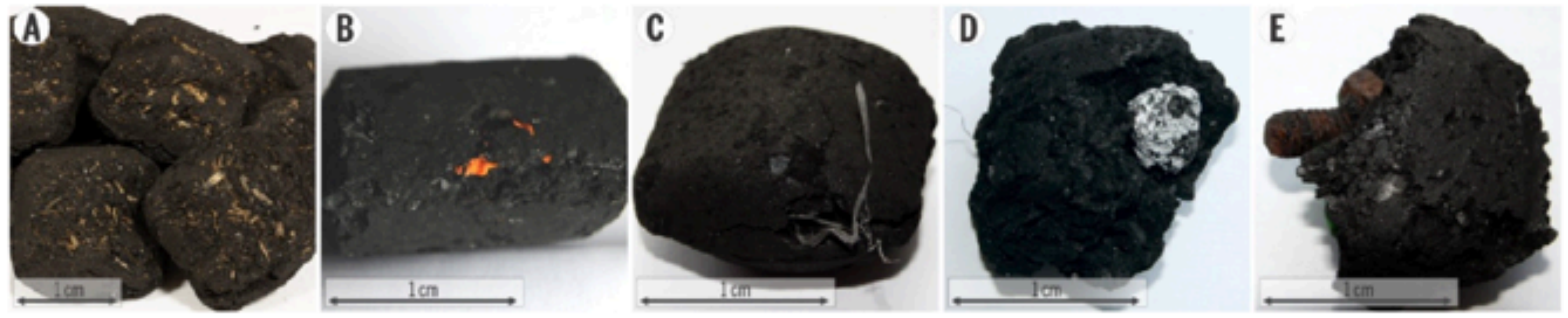
Presentations

- Allison Ray and Bryon Donohoe, "Unveiling Signatures of Feedstock Variability," FCIC Webinar Series, April 29, 2021.
- Bryon Donohoe, Yining Zeng, Amber Hoover, Renee Happs, Juan Leal, Troy Semelsberger, and Allison Ray, "Lignin variability induced by biological degradation during storage and its impact on mechanical properties, pretreatment, hydrolysis, and upgrading," Symposium for Biomaterials, Fuels, and Chemicals, Virtual Conference, April 26–28, 2021.
- Ling Ding, Allison Ray, and Bryon Donohoe, “Time Domain-NMR for resolution of bound and free water in anatomical fractions of pine residues and corn stover as functions of biological degradation,” Symposium for Biomaterials, Fuels, and Chemicals, Virtual Conference, April 26–28, 2021.
- Juan Leal, Travis Rouse, Lily Cheng, Eric Meierdierks, Cameron Moore, Andrew Sutton, Amber Hoover, Bryon Donohoe, Allison Ray, and Troy Semelsberger, "Impacts of biologically induced heating on surface energy, wettability & cohesion of corn stover,” Symposium for Biomaterials, Fuels, and Chemicals, Virtual Conference, April 26–28, 2021.
- Allison E. Ray, Ling Ding, Kuan-Ting Lin, Kenneth Sale, Ning Sun, Troy Semelsberger, and Bryon S. Donohoe, "Multiscale characterization of lignocellulosic biomass: Fundamental insights into feedstock variability origins,” American Chemical Society Fall 2021 Meeting, August 22–26, 2021.
- B.S. Donohoe and L. Ding, "Engineering and deconstruction of biomass and recalcitrant polymers,” Co-conveners at 2022 SBFC Symposium on Biomaterials, Fuels, and Chemicals Session, Astor Crowne Place, New Orleans, LA, May 1–4, 2022.
- I. Ruhl, S. Haugen, L. Ding, and D. Salvachúa, "Identification of critical material attributes in lignin streams based on *Pseudomonas putida* performance," 44th SBFC Symposium on biomaterials Fuels and Chemicals, May 1–4, 2022.
- W. Li and L. Ding, "Drought impact on anatomical fractions of corn stover as a bioenergy feedstock," 2022 FCIC Annual Meeting, June 7–9, 2022.

Outreach: International Inter-Laboratory Study to Identify Contamination in Biomass Fuels

Testing the Reproducibility of Biomass Fuels Component Identification Using Reflected Light Microscopy

The Centre for Biomass Energy Research and Education at the University of Silesia in Katowice, Poland

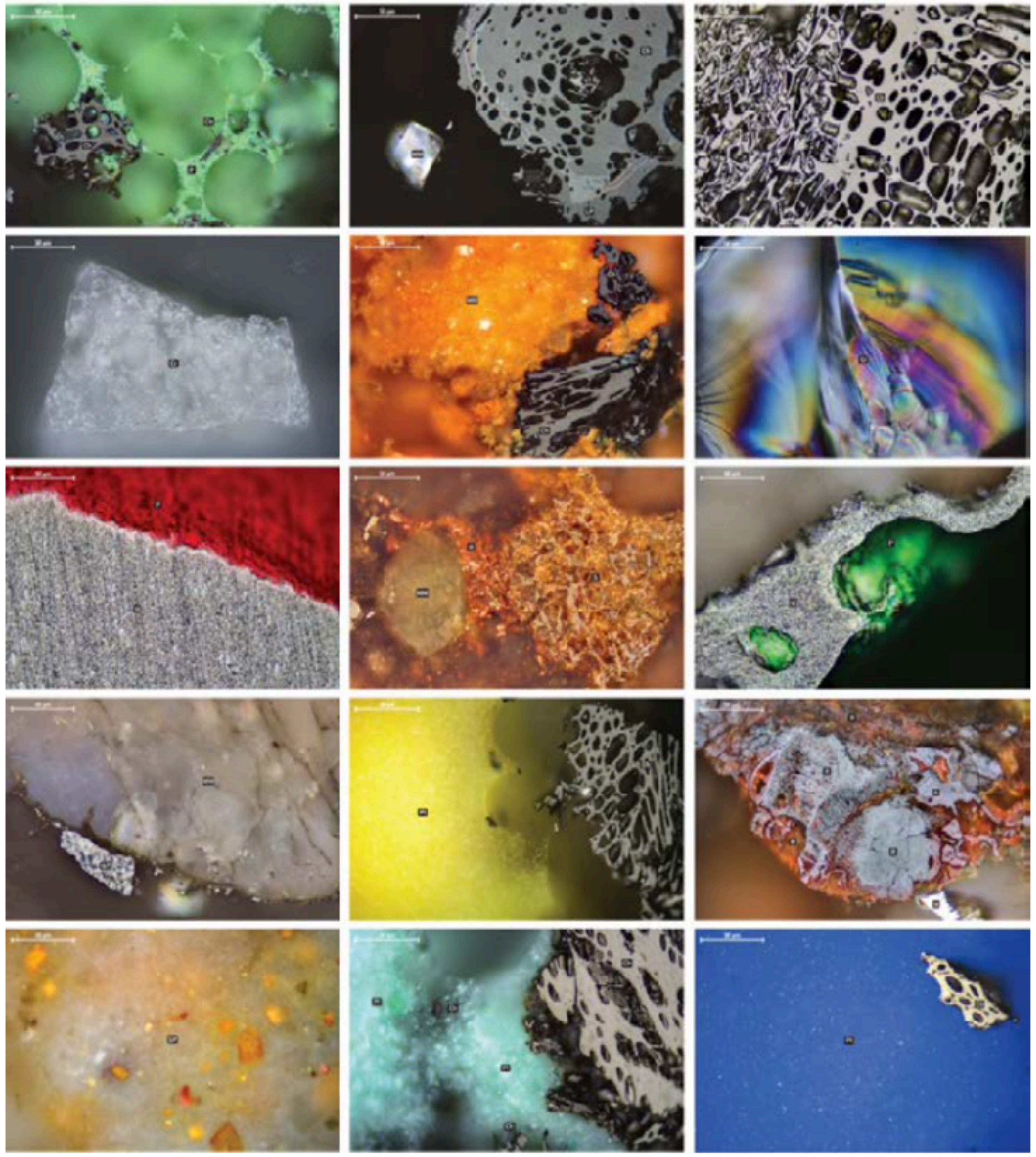


Photographs illustrating megascopic impurities found in charcoal briquettes. A – briquettes with high biomass (6.1 vol. %), B–C – briquette containing a piece of plastic, D – briquette containing a piece of metal (aluminum foil from candy), E – briquette containing a metal screw.

Wood pellets having very high contents of impurities that are visible megascopically in raw samples (A–C) and a microscope plug (D). A – ash, Bk – bark, C – coal, Gl – glass, M – metal, O – binder, Pl – plastic. 1 cm = 0.39 inch.

Expands on earlier studies on charcoal and pellets to agricultural, forestry, MSW, and industrial residues.

- We are contributing expertise in biomass microscopy and image analysis.



Photomicrographs of various contaminants of solid biomass in reflected light.

Image Analysis for Rapid Assessment of Corn Stover

Tools

Image analysis tools for screening and classifying biological degradation and soil contamination

Description

- Image analysis to extract features from RGB color space to investigate variations in critical material attributes from the chemical composition of corn stover.
- Fourier-transform infrared (FT-IR) suggested a correlation between red band intensity and biological degradation.
- Surface texture analysis distinguished ash content.

Value

- Rapid screening tools can be deployed for in-field assessment of biomass quality or biorefinery operators for in-line sorting and process optimization.

Potential Customers

- Image analysis and other rapid characterization tools to understand and describe corn stover and bioenergy feedstock quality during in-field or over-belt applications to support industrial sorting operations based on quality or contaminants.

L. Ding, A.N. Hoover, R.M. Emerson, K.-T. Lin, J.N. Gruber, B.S. Donohoe, J.L. Klinger, et al., "Image Analysis for Rapid Assessment and Quality-Based Sorting of Corn Stover," *Front. Energy Res.* 2022, 10, 837698, http://doi.org/10.3389\fenrg.2022.837698

Nanomechanical Mapping of Pine Tissue

Knowledge

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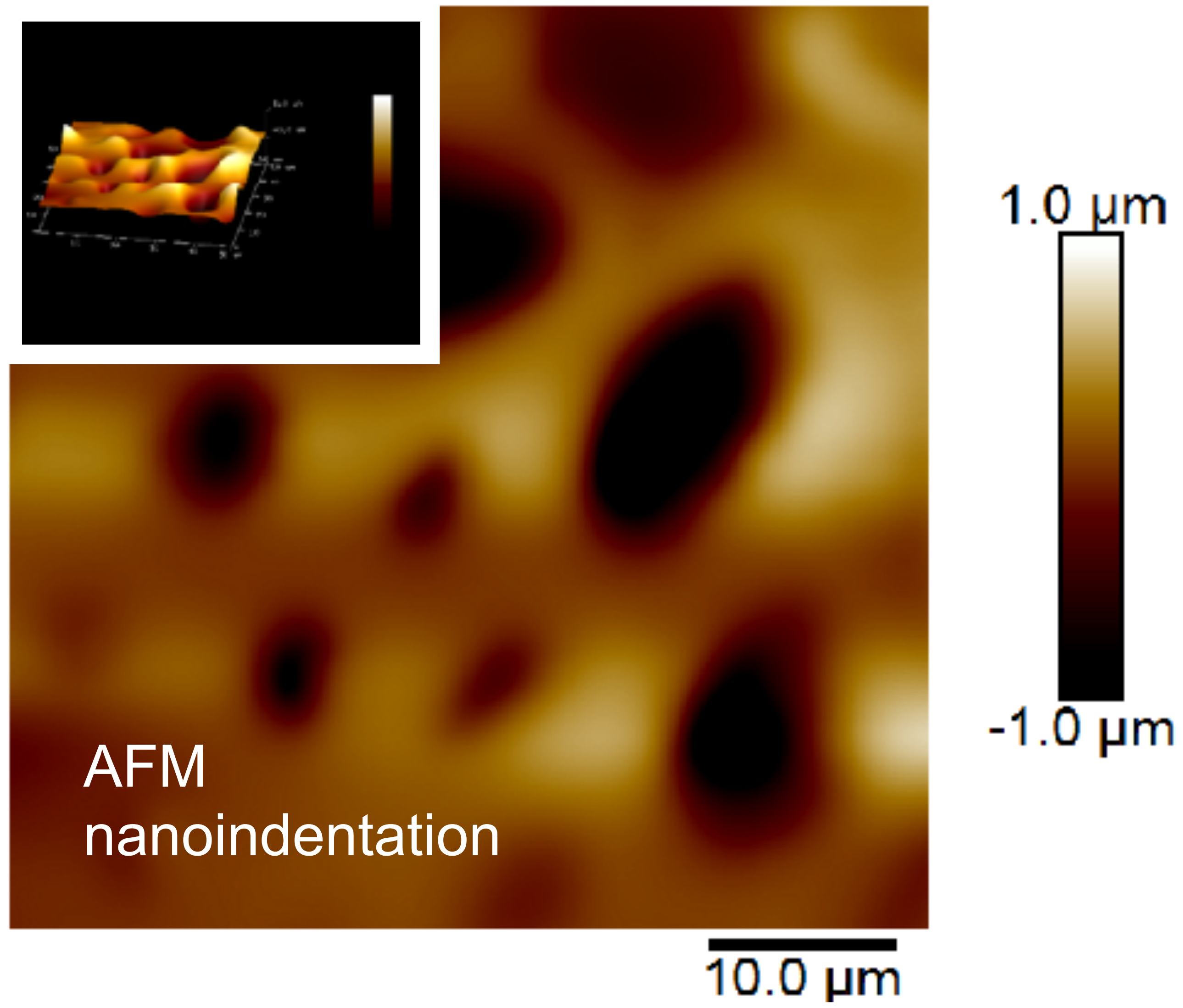
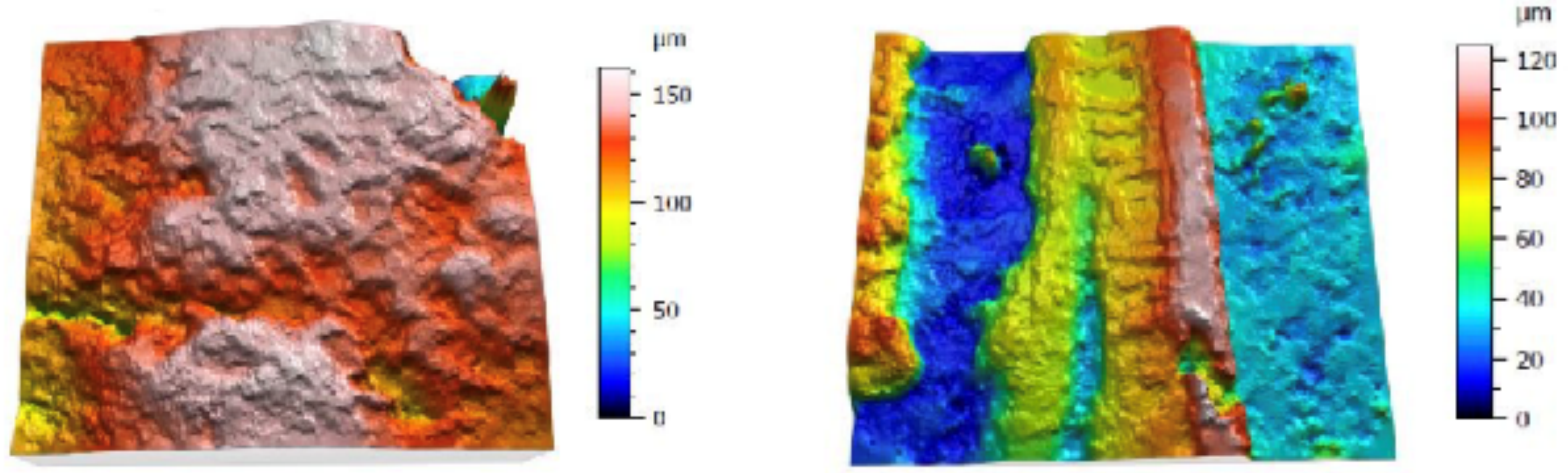
Test hypothesis that pine tissue fractions differ in nano-mechanical properties that impact materials handling and preprocessing



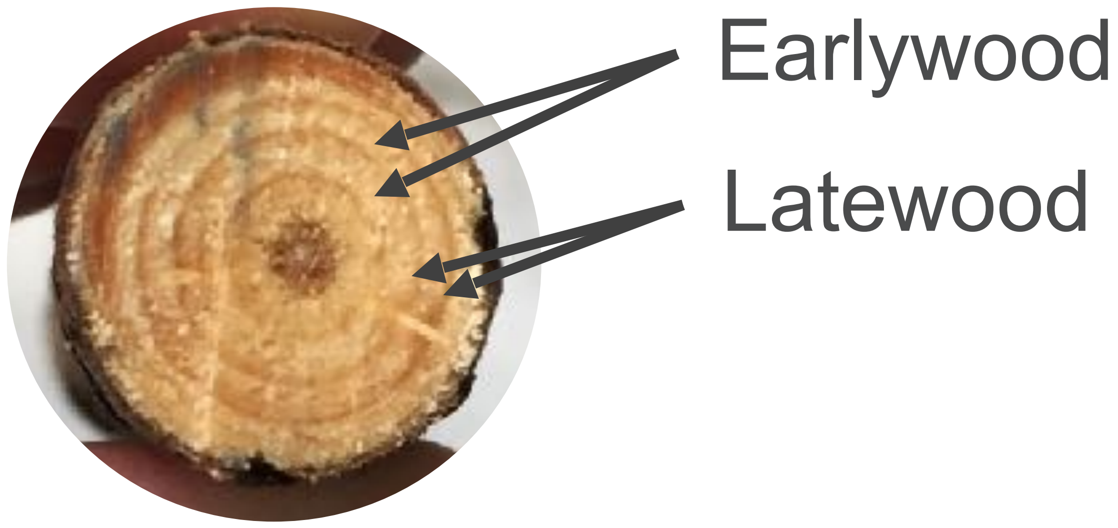
Surface roughness bark (left), needle (right)



A. Hoover et al. Manuscript in preparation

Knowledge Gap

- How do nano-mechanical properties vary by tree age (13- vs. 23-year-old) and among loblolly pine tissue fractions?
- Elastic modulus mapping of (1) needles, (2) early- and latewood from branches, and (3) bark from branches.



Achievement

- Fundamental nano-mechanical attributes support the examination of how multiscale attributes in pine and stover anatomical fractions impact behavior in preprocessing and conversion.

Relevance

- Knowledge of the effects of intrinsic/supply chain factors on biomass physical/mechanical material attributes and how their impacts downstream can inform harvest and collection best management practices and biorefinery risk management on the origins of biomass variability and how the variability may be modified.