DOE Bioenergy Technologies Office (BETO) 2021 Project Peer Review

Feedstock Variability

March 15, 2021
Feedstock Conversion Interface Consortium (FCIC)

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fcic
FEEDSTOCK-CONVERSION INTERFACE CONSORTIUM

FCIC Task Organization

Feedstock → Preprocessing → Conversion

- **Task 2: Feedstock Variability**
- **Task 5: Preprocessing**
- **Task 6: Conversion High-Temp**
- **Task 7: Conversion Low-Temp**
- **Task 1: Materials of Construction**
- **Task 3: Materials Handling**

Enabling Tasks

- **Task X: Project Management**
- **Task 4: Data Integration**
- **Task 8: TEA/LCA**

Task X: Project Management: Provide scientific leadership and organizational project management

Task 1: Materials of Construction: Specify materials that do not corrode, wear, or break at unacceptable rates

Task 2: Feedstock Variability: Quantify & understand the sources of biomass resource and feedstock variability

Task 3: Materials Handling: Develop tools that enable continuous, steady, trouble free feed into reactors

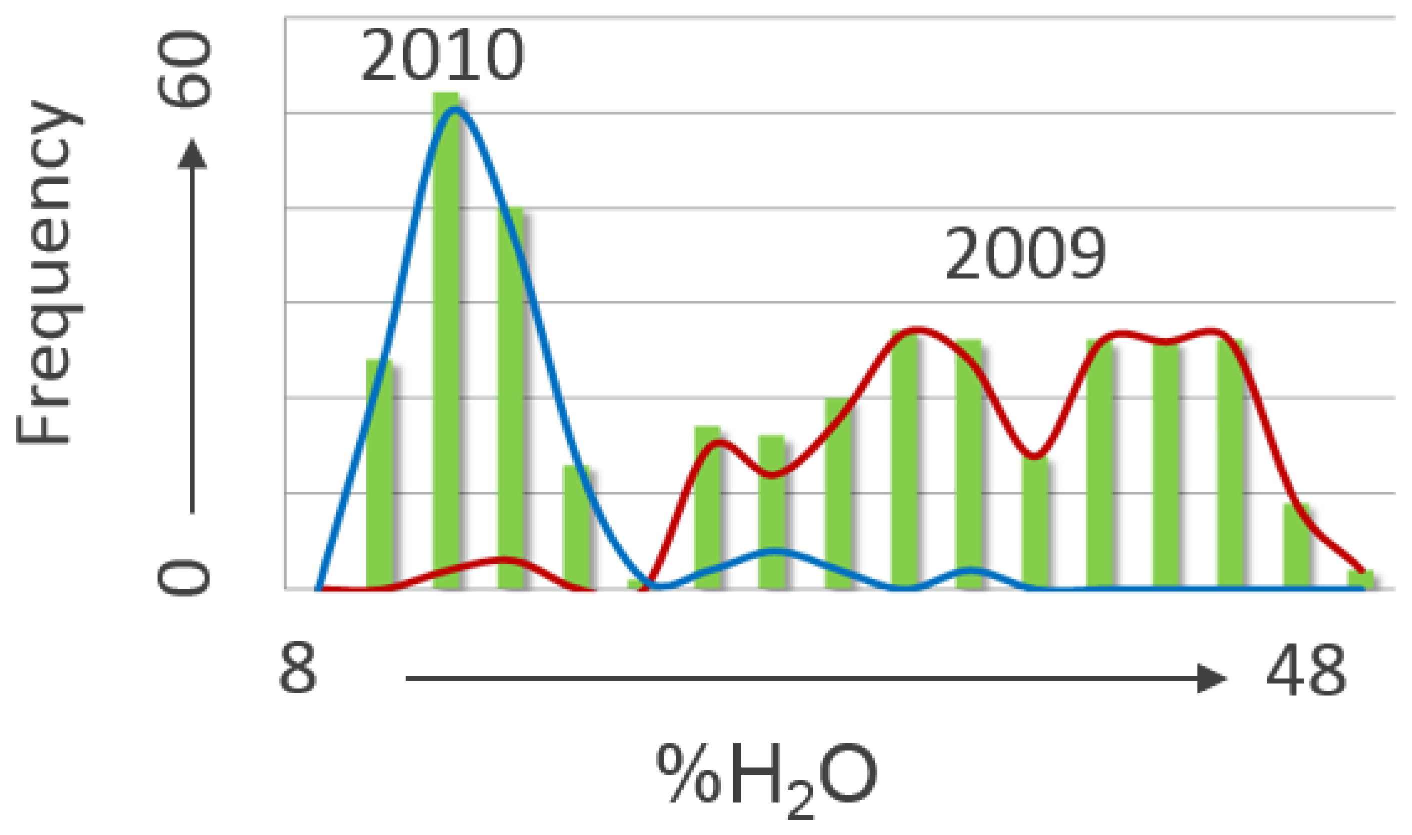
Task 4: Data Integration: Ensure the data generated in the FCIC are curated and stored – FAIR guidelines

Task 5: Preprocessing: Enable well-defined and homogeneous feedstock from variable biomass resources

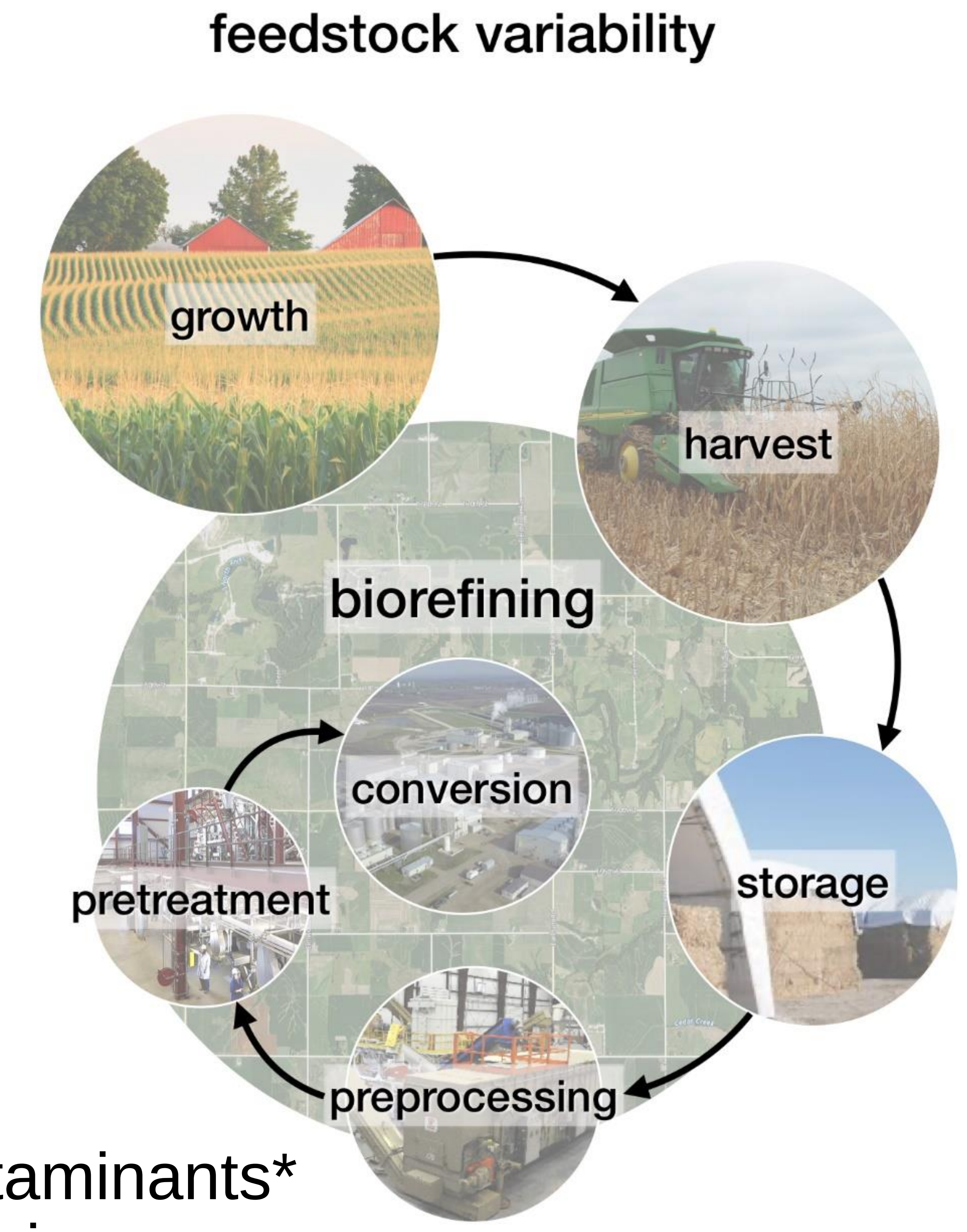
Task 6 & 7: Conversion (High- & Low-Temp Pathways): Produce homogeneous intermediates to convert into market-ready products

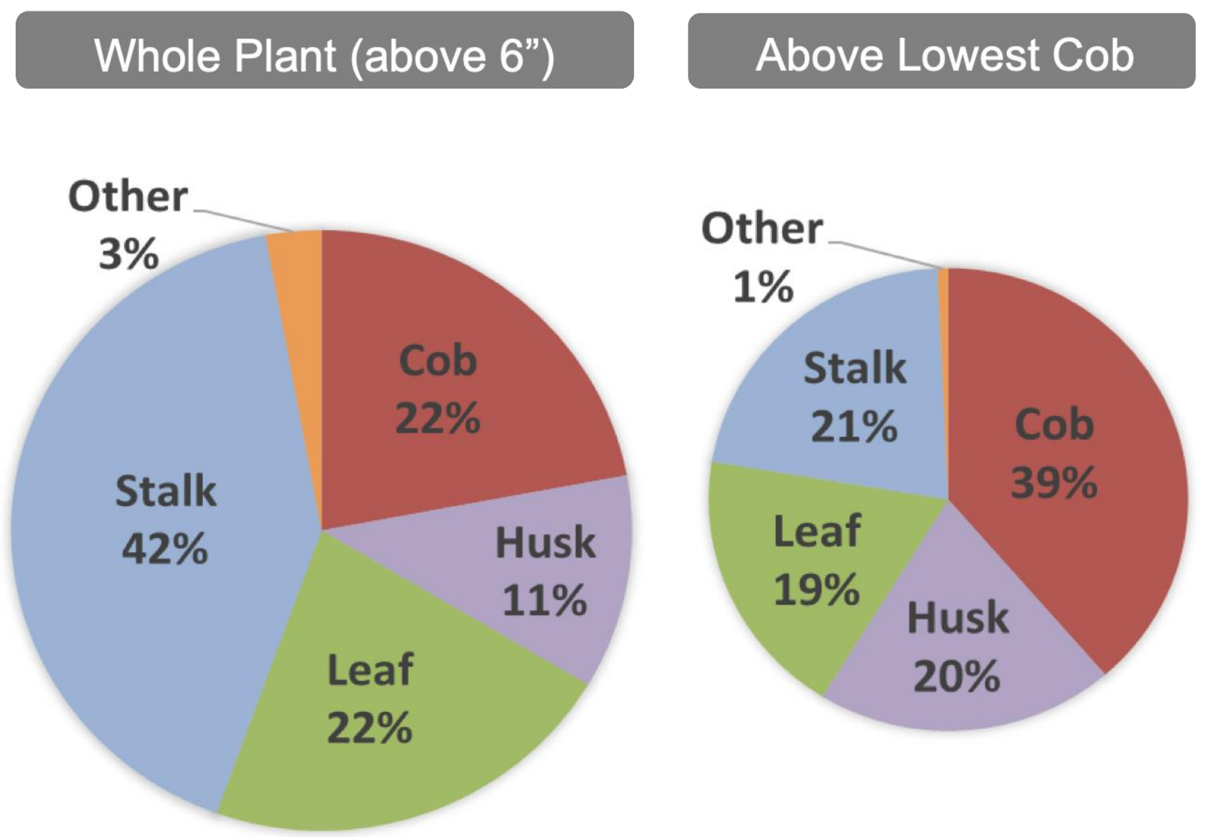
Task 8:Crosscutting Analyses TEA/LCA: Valuation of intermediate streams & quantify variability impact

*Feedstock variability cited as a major operational challenge**



moisture content variability in corn stover





anatomical fractions are a source of variability

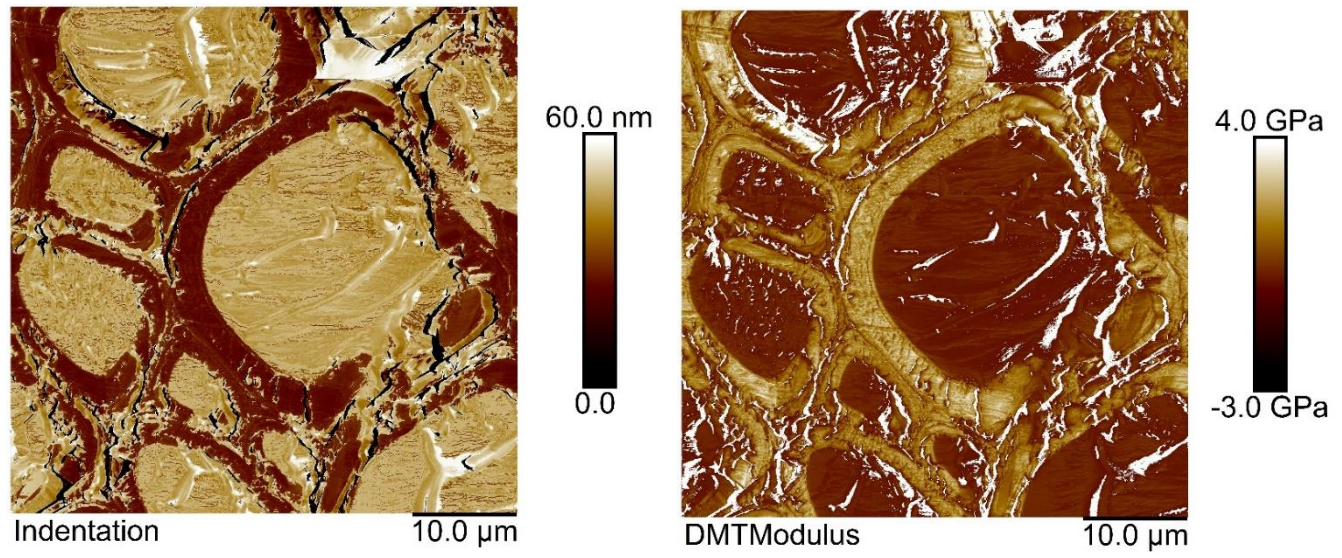
biological degradation of corn stover during field-side storage alters bulk composition and structural integrity

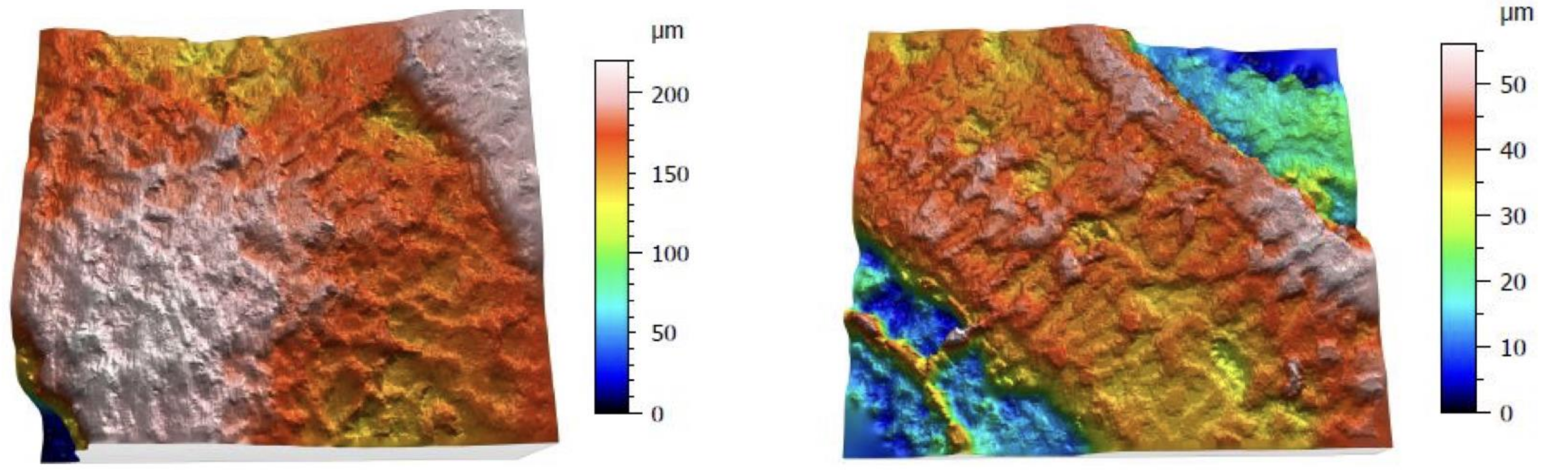
- Intrinsic ash, moisture, and soil contaminants* noted as critical factors that impact biomass quality, process uptime and throughput

*Biorefinery Optimization Workshop Summary Report (October 2016), USDOE EERE Bioenergy Technologies Office

Project Overview

- **Objective:** Identify & quantify the initial distribution of feedstock CMAs and inform strategies to reduce and manage this variability
- **Current limitations:** The complexity of lignocellulosic biomass and feedstock variability has been largely ignored by the biorefining industry. Industry lacks understanding of CMAs/CQAs, their magnitude, range, and distribution in available resources
- **Relevance:** Provides industry with characterization tools and CMA variability data that inform 1) storage and harvest best practices, 2) feedstock quality, and 3) selection of process configurations that manage variability from field through conversion
- **Risks:** Translating fundamental understanding of the multi-dimensional mechanisms that generate feedstock variability into knowledge and tools that can be easily transferred to industry remains a challenge.





Feedstock Variability Team: Collaborating Across Six Labs

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FEEDSTOCK-CONVERSION INTERFACE CONSORTIUM


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Oslo Jacobson


Ethan Oksen

1 – Management

Subtask	Lead(s)	Major Responsibilities
2.1 Molecular-scale Inorganics	C. Li (previously INL), L. Ding (INL)	Quantification and localization of inorganic species in corn stover for understanding of storage and aging impacts
2.2 Molecular-scale Organics	A. Ray (INL), N. Sun (LBNL)	Variability of organic attributes in microbially-degraded corn stover: implications for quality
2.3 Micro-scale	B. Donohoe (NREL), T. Semelsberger (LANL)	Impacts of biological heating and degradation during bale storage on the surface properties
2.4 Macro-scale	A. Hoover (INL), E. Webb (ORNL)	Image analysis for rapid assessment and sorting of corn stover based on quality
2.5 Data Analytics	K. Sale (SNL)	Biomass agnostic approach to evaluate how differences in feedstock features relate to downstream processes

- **Risks:** Lack of fundamental data, understanding of attribute-impact relationships, and integration across tasks. Task 2 mitigates these risks through 1) coupling fundamental characterization and data-driven approaches; 2) harnessing diverse capabilities of interdisciplinary, multi-institution team; and 3) joint FCIC milestones, leveraging data, methods, samples, etc. to inform other BETO consortia and BETO core programs.
- **Communication strategy:** 1) Participate in weekly FCIC task-lead meetings, 2) discuss ongoing projects and upcoming deliverables in bi-monthly task meetings, 3) present updates to BETO program managers quarterly, and 4) present updates to our advisory board liaison.

2 – Approach

Technical Approach:

- Multiscale characterization to identify, quantify, and understand biomass feedstock CMAs with subtasks focused on understanding how the structural and physicochemical attributes of cell wall architecture and biomass tissue structure underlie flow behavior and the mechanical and thermochemical deconstruction of biomass.
- Coupling analytical tools, advanced characterization, and data analytics to quantify properties that reveal potential CMAs.
- Data analytics to group material attributes and explain origins of their variability.

Challenges:

- Developing robust characterization beyond traditional compositional analysis.
- Stretching beyond the attributes of moisture, total ash, and particle size.
- Establishing the criticality of newly quantified and understood feedstock attributes.

Metrics: 1) Fundamental characterization of biomass variability at multiple scales; 2) knowledge and tools to inform technology deployment; 3) distributions of CMAs that inform operational envelopes and enable TEA/LCA; 4) foundation of an attribute-driven approach for management of feedstock quality.

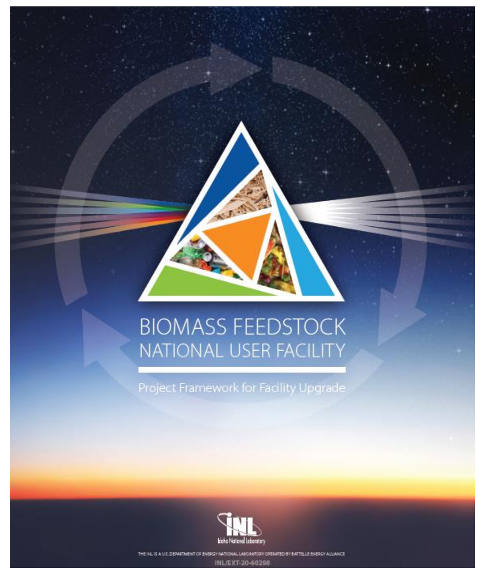
3 – Impact

Impact:

- Providing characterization tools and CMA variability data that informs 1) storage and harvest best practices, 2) feedstock quality evaluation, and 3) selection of process configurations that manage variability from field through conversion
- Feedstock suppliers, process designers, equipment manufacturers, and investors will derive value from fundamental knowledge of economic drivers that are critical to de-risking the industry

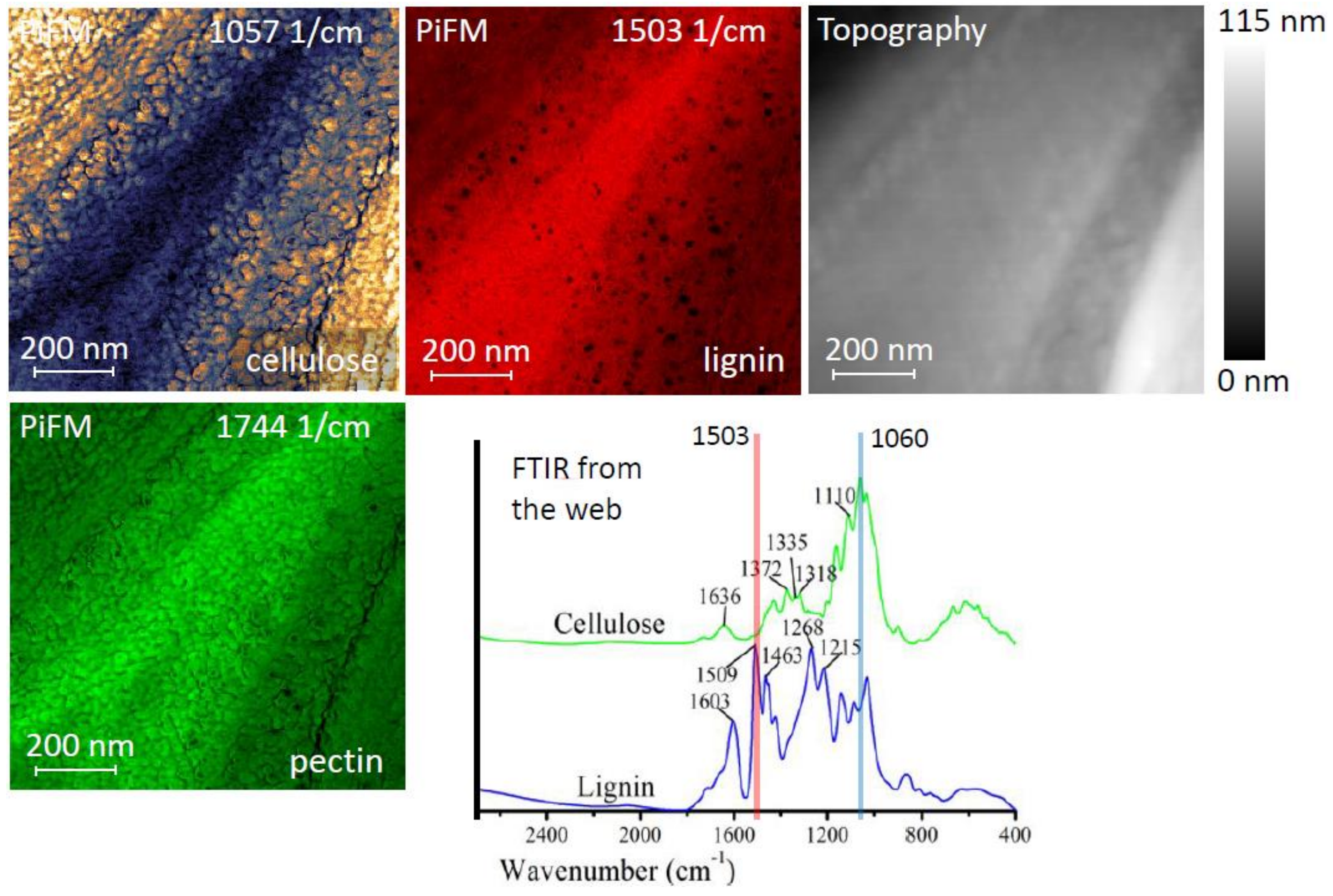
Dissemination:

- Issue concise, readable, concept driven, and data supported publications in scientific journals (11 papers FY19-21)
- Present at scientific conferences, and to other research groups and institutions to generate interest in our results (7 talks, 5 accepted abstracts FY19-21)
- FCIC Feedstock Variability webinar is planned for April 2021

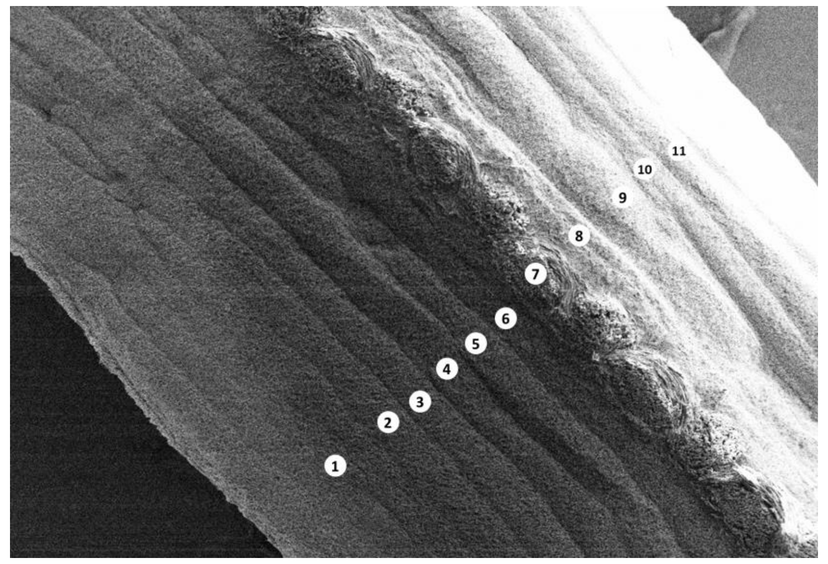


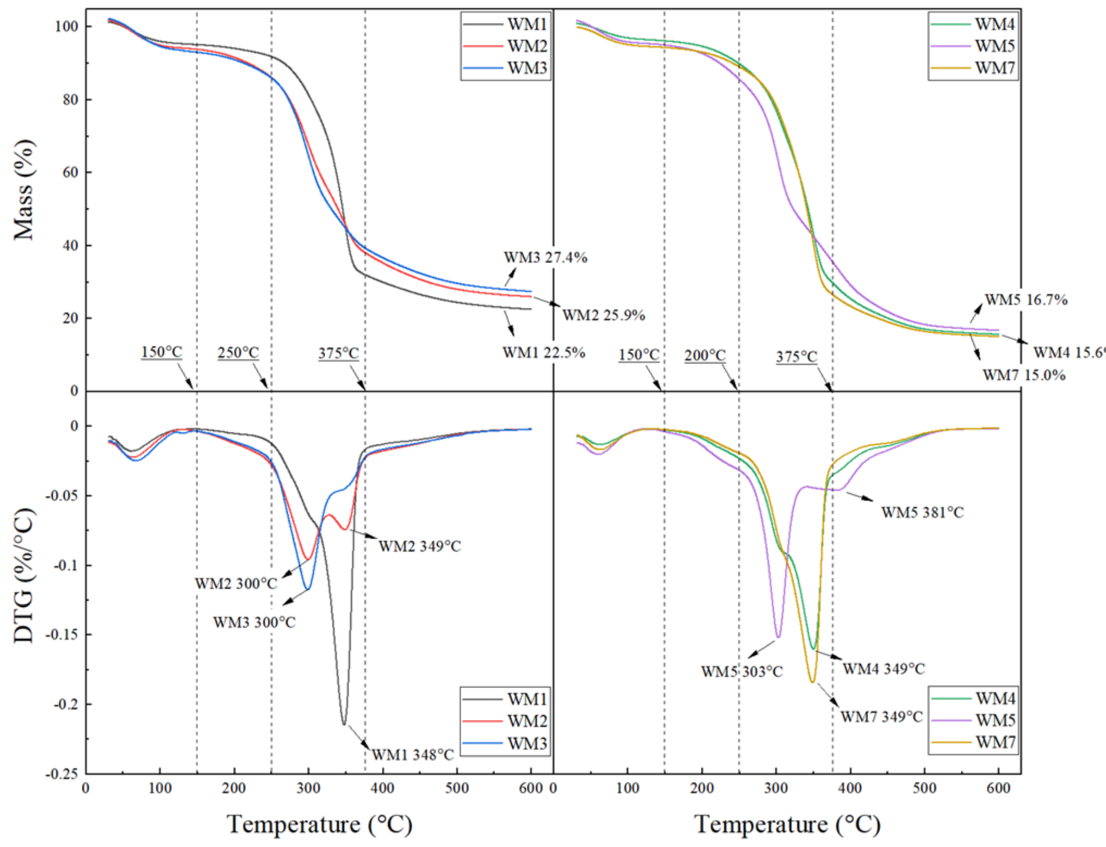
Industrial engagement

- **Mycoworks:** Characterization of mycelium biomass after solid fermentation (INL, LBNL)
- **Molecular Vista:** Photo-induced Force Microscopy analysis of self heated corn stover samples (NREL, LBNL, INL)
- **LECO:** Invited to present novel, molecular characterization approach at PittCon, *Industrial Applications of GCxGC* (INL)
- **JENIKE® & JOHANSON:** surface characterization and flow behavior of biomass solids (LANL)
- **Green Carbon International LLC**



PiFM of wood cell wall

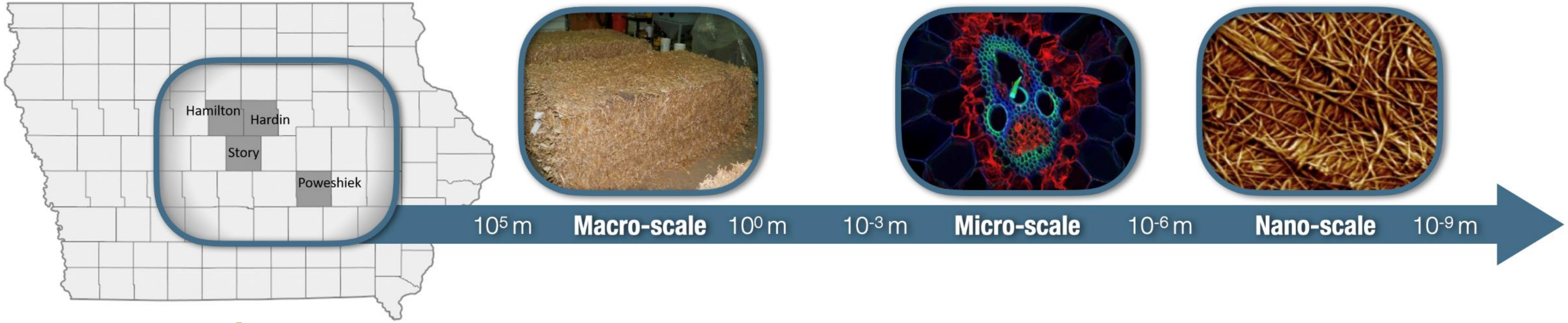




SEM image of mycelium layers, and thermogravimetric analysis (TGA) of mycelium samples under nitrogen.

4 – Progress and Outcomes

Biomass attributes vary at all spatial scales



Motivation

Physicochemical and structural variability exist at multiple scales;

each scale offers unique insights to the sources of variability and material attributes that impact the biomass value chain.

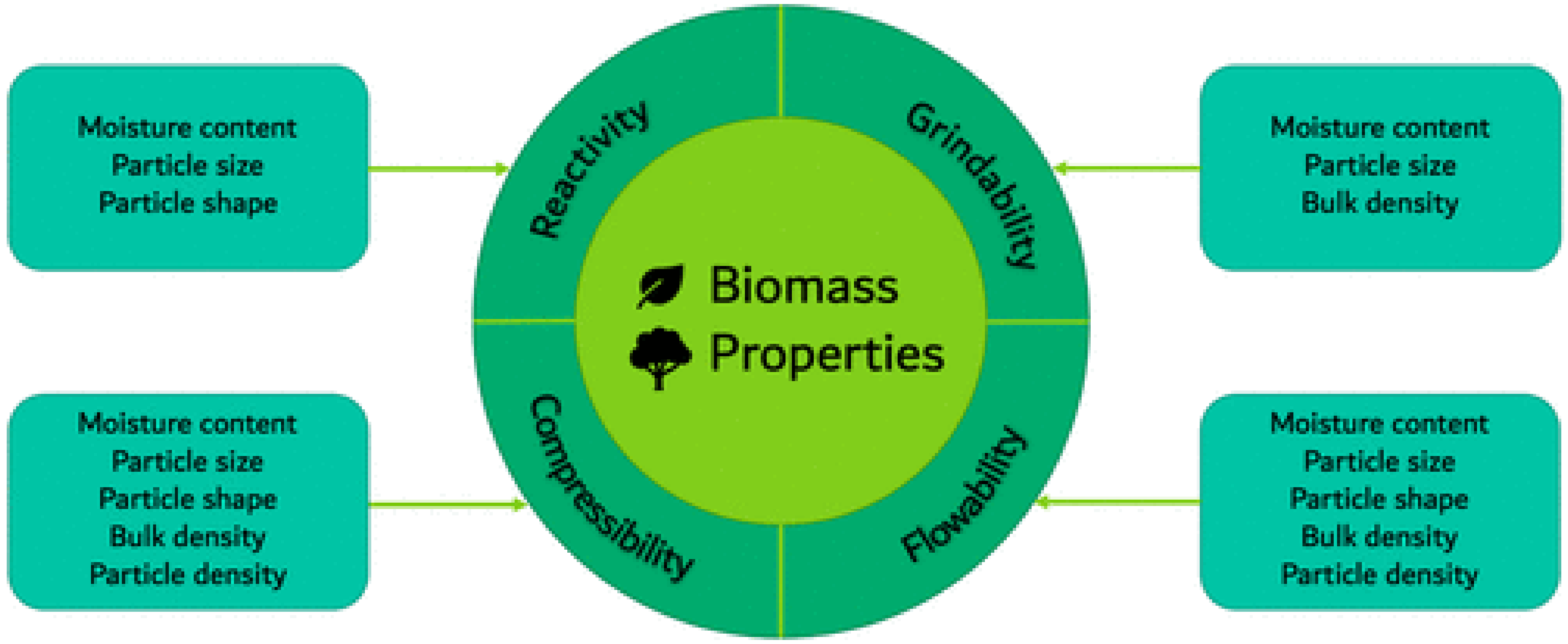
Emergent properties increase the complexity and cost of biorefinery operations.

Multiscale Characterization of Lignocellulosic Biomass Variability and Its Implications to Preprocessing and Conversion: a Case Study for Corn Stover
A.E. Ray, C.L. Williams, A.N. Hoover, C. Li, K.L. Sale, R.M. Emerson, J. Klinger, E. Oksen, A. Narani, J. Yan, C.M. Beavers, D. Tanjore, M. Yunes, E. Bose, J.H. Leal, J.L. Bowen, E.J. Wolfrum, M.G. Resch, T.A. Semelsberger, and B.S. Donohoe. *ACS Sustainable Chemistry & Engineering* 2020 8 (8), 3218-3230, DOI: 10.1021/acssuschemeng.9b06763

Characterizing variability in lignocellulosic biomass

Knowledge

Provided a critical review of advanced methods for characterizing a broader array of feedstock variability attributes



Current Knowledge Gap

- Feedstock variability is a significant barrier to the scale-up and commercialization of lignocellulosic biofuel technologies

Achievement

- Reviewed several advanced analytical methods that measure density, moisture content, thermal properties, flowability, grindability, rheology properties, and micromorphology
- Examined methods that have not traditionally been used to characterize lignocellulosic feedstocks but have the potential to bridge gaps in our explanation of variability

Relevance

- Physical and mechanical properties of feedstock in unit operations, studied with advanced analytical methods, can better explain variability

Characterizing Variability in Lignocellulosic Biomass: A Review
J. Yan, O. Oyedeji, J.H. Leal, B.S. Donohoe, T.A. Semelsberger, C. Li, A.N. Hoover, E. Webb, E.A. Bose, Y. Zeng, C.L. Williams, K.D. Schaller, N. Sun, A.E. Ray, and D. Tanjore
ACS Sustainable Chemistry & Engineering 2020 8 (22), 8059-8085, DOI: 10.1021/acssuschemeng.9b06263

Inorganics content impacts work of cohesion in biomass samples

Knowledge

Current Knowledge Gap

- Variations in feedstock attributes directly impact bulk solids handling and processing of biomass, an identified area of biorefinery difficulty

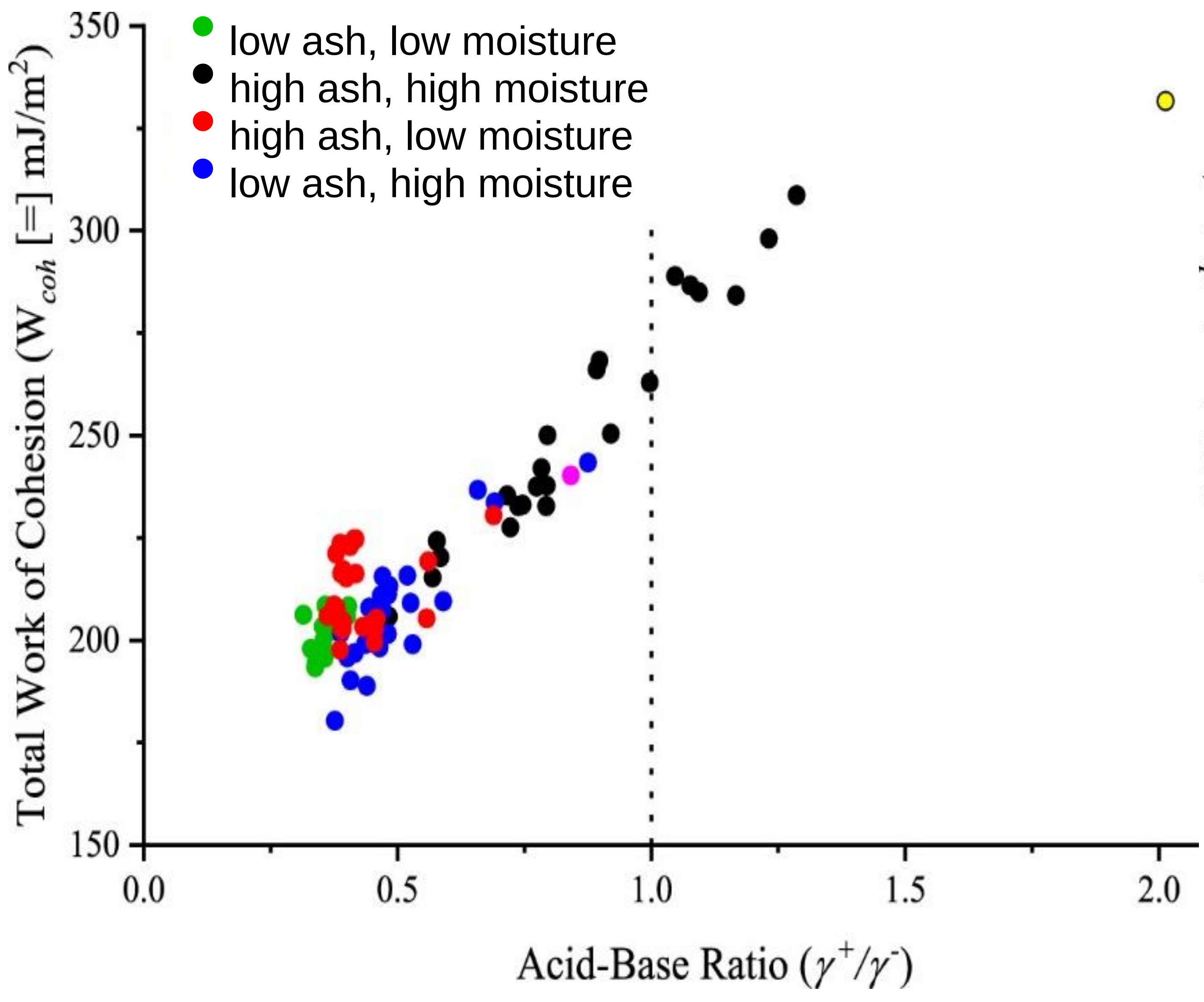
Achievement

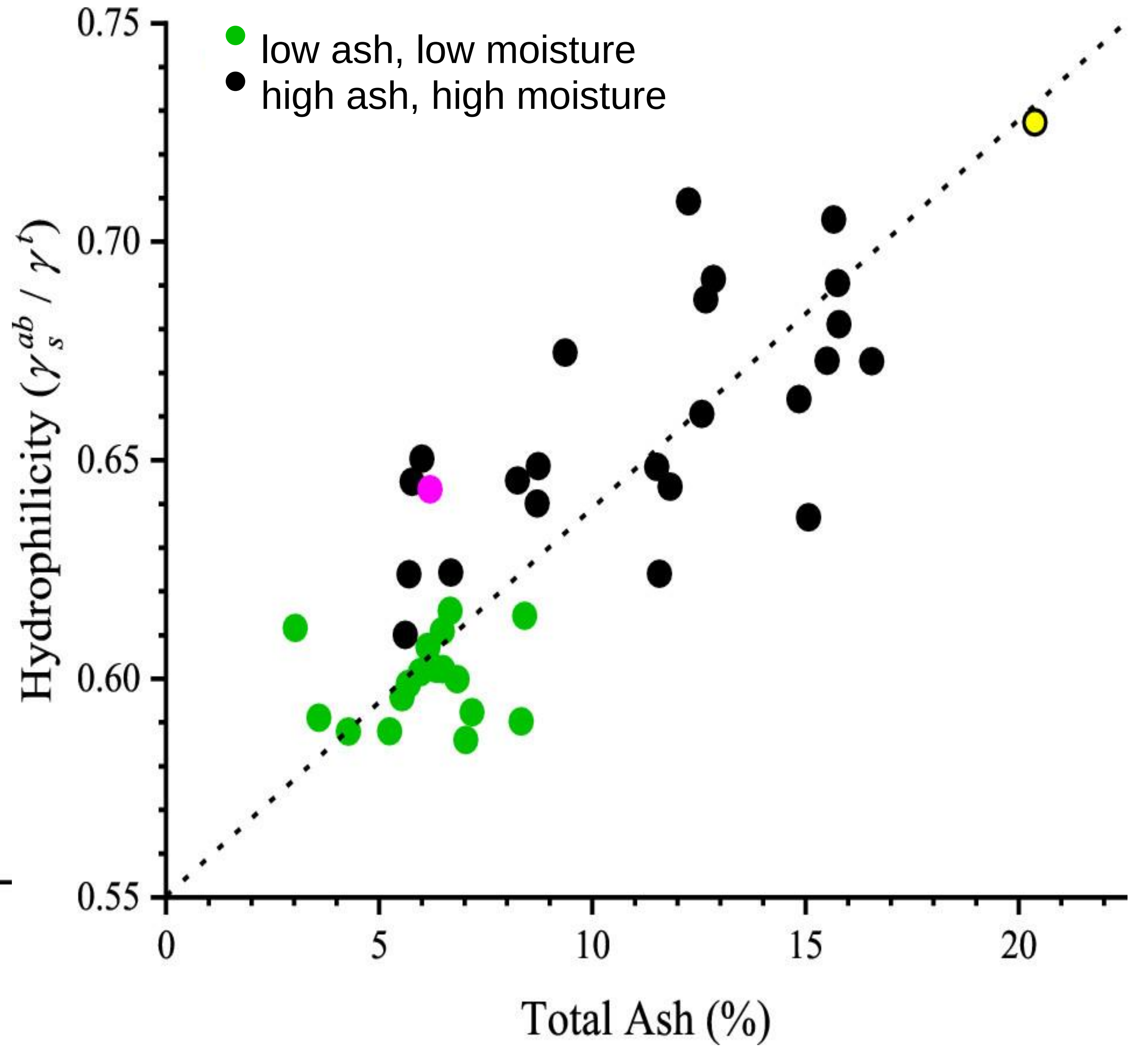
- Measured and described the impacts of inorganics on surface energy, wettability, and cohesion of corn stover
- Found that the acid component of surface energy increased with increasing ash content, particularly ash contents greater than 10%. Negligible effects with ash content were observed on both the dispersive and base components of surface energy

Relevance

- Provides fundamental understanding of thermophysical properties that give rise to bulk solids handling and transport challenges related to segregation, agglomeration, rat-holing, arching, and discontinuous flow patterns

Determined that the work of cohesion and wettability (hydrophilicity) increased with increasing total ash content



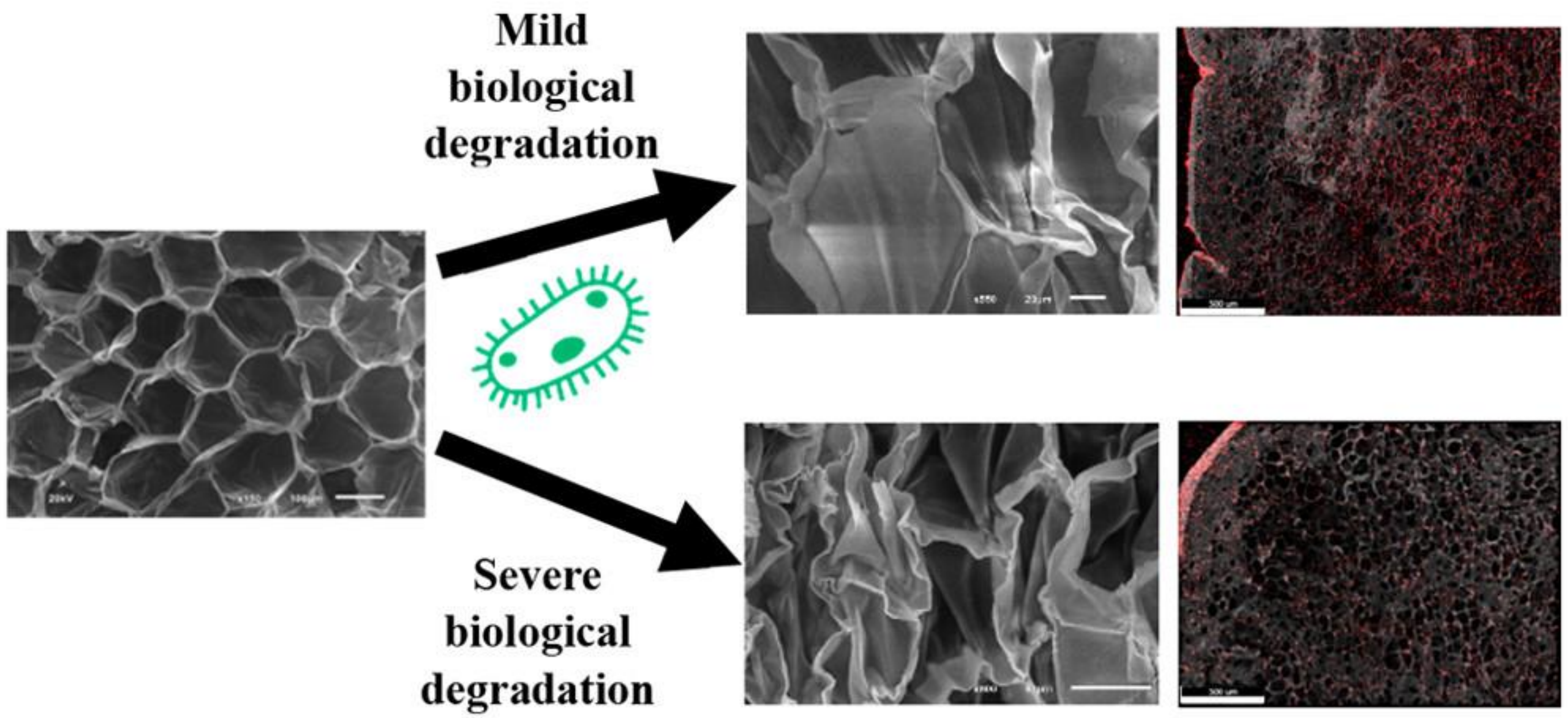


Impacts of Inorganic Material (Total Ash) on Surface Energy, Wettability, and Cohesion of Corn Stover
J.H. Leal, E.L. Torres, W.T. Rouse, C.M. Moore, A.D. Sutton, A.N. Hoover, C. Li, M.G. Resch, B.S. Donohoe, A.E. Ray, and T.A. Semelsberger
ACS Sustainable Chemistry & Engineering 2020 8 (4), 2061-2072, DOI: 10.1021/acssuschemeng.9b06759

Characterizing inorganic species variability in corn stover fractions

Knowledge

Inorganic species mapping revealed that biological heating and degradation resulted in translocation of silica from the pith to the outer epidermal tissues



Current Knowledge Gap

- Conventional approaches are based on a total ash content of bulk materials without tracking or understanding of the form, fate, or impacts of individual species

Achievement

- Conducted a first-of-a-kind study of dynamic elemental variability and distributions observed in corn stover fractions as functions of storage and biological heating
- Characterized cell wall structure and localized inorganic species variability in harvested and stored corn stover fractions

Relevance

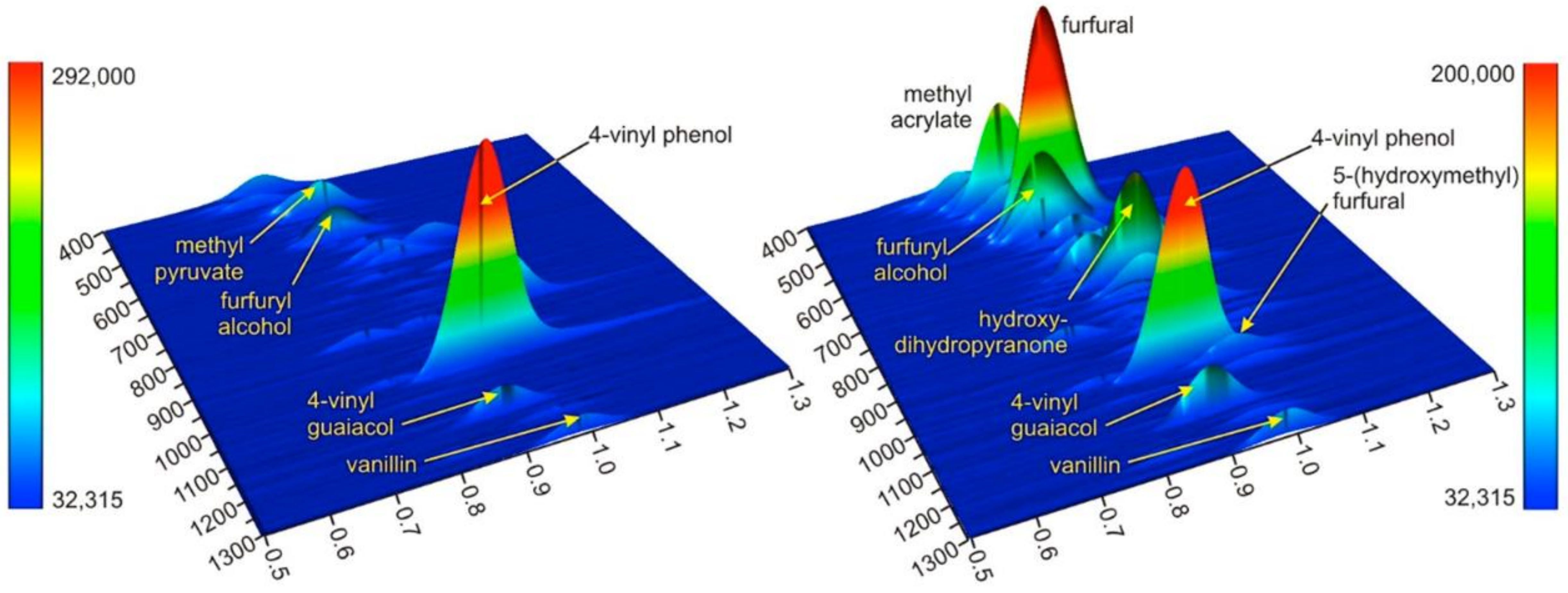
- Provides fundamental understanding to inform strategies for harvest and collection, abrasive wear mitigation, selective biomass preprocessing technologies, and equipment design

Characterization and Localization of Dynamic Cell Wall Structure and Inorganic Species Variability in Harvested and Stored Corn Stover Fractions as Functions of Biological Degradation
C. Li, P. Kerner, C.L. Williams, A. Hoover, and A.E. Ray
ACS Sustainable Chemistry & Engineering 2020 8 (18), 6924-6934, DOI: 10.1021/acssuschemeng.9b06977

Characterizing bale degradation

Knowledge

Findings suggest that biological heating disrupts cell wall structure, fragmenting the hemicellulose or cellulose chains



mild biological degradation | severe biological degradation

Current Knowledge Gap

- Biomass degradation during long-term storage negatively affects conversion performance and value of the biomass

Achievement

- Used py-GC/GC to identify and quantify breakdown products in corn stover samples with different biological degradation profiles
- Identified and quantified hemicellulose modification due to biological degradation using analytical pyrolysis and multidimensional GCMS

Relevance

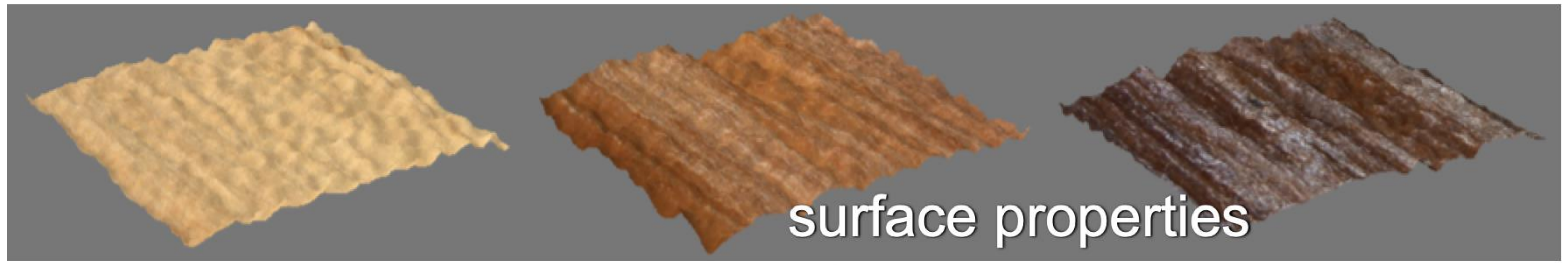
- Stakeholders can use this technique to rapidly characterize biomass feedstock degradation and correlate with downstream conversion performance
- FCIC researchers were invited by the py-GC/GC instrument manufacturer (LECO) to present the work in an upcoming conference

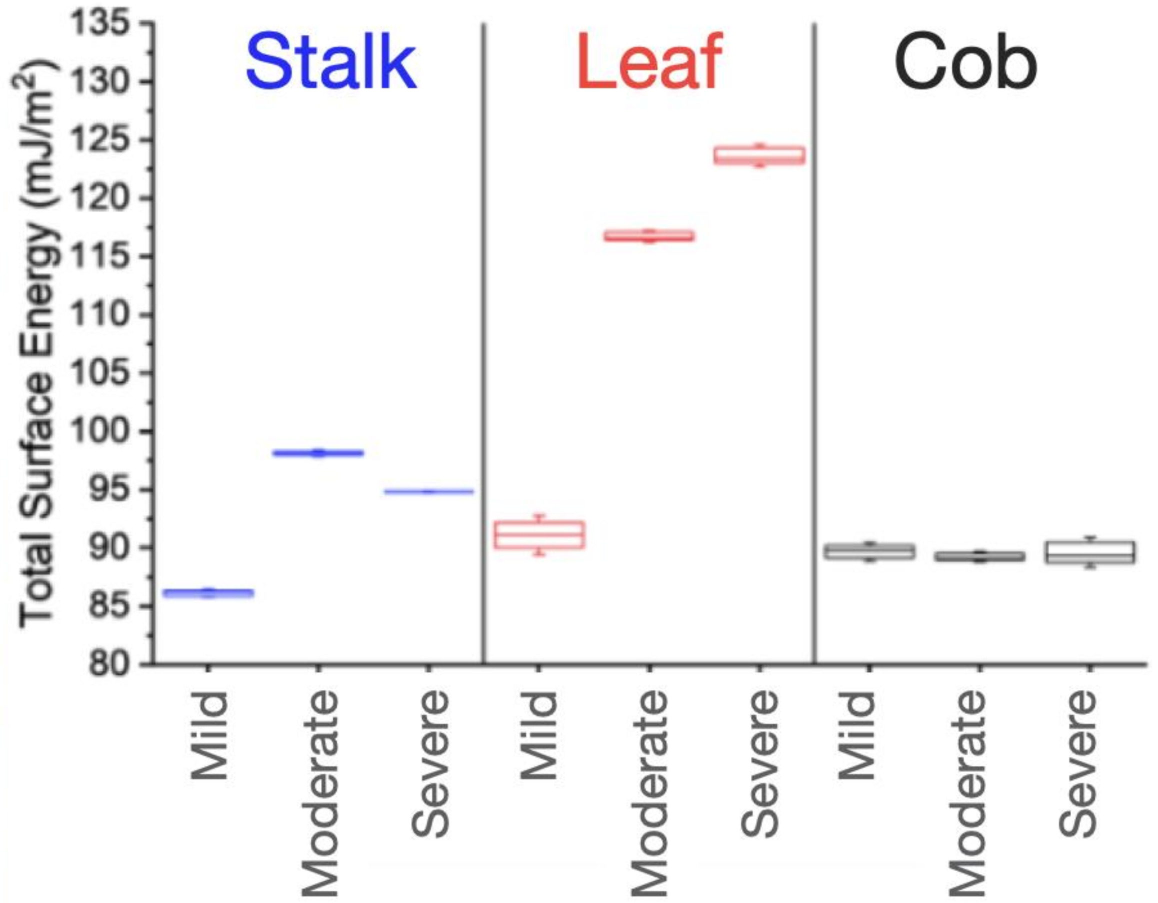
Signatures of Biologically Driven Hemicellulose Modification Quantified by Analytical Pyrolysis Coupled with Multidimensional Gas Chromatography Mass Spectrometry
G.S. Groenewold, B. Hodges, A.N. Hoover, C. Li, C.A. Zarzana, K. Rigg, and A.E. Ray
ACS Sustainable Chemistry & Engineering 2020 8 (4), 1989-1997, DOI: 10.1021/acssuschemeng.9b06524

Measuring changes in biomass surface properties

Knowledge

Some tissue surfaces like leaves were dramatically changed by degradation, while others like cobs were relatively unaffected





Impacts of Biological Heating and Degradation during Bale Storage on the Surface Properties of Corn Stover
E. Bose, J.H. Leal, A.N. Hoover, Y. Zeng, C. Li, A.E. Ray, T.A. Semelsberger, and B.S. Donohoe
ACS Sustainable Chemistry & Engineering, 2020, DOI: 10.1021/acssuschemeng.0c03356

Current Knowledge Gap

- Critical sources of variability in chemical, physical and mechanical properties of biomass feedstocks that impact biomass processing and conversion are not known

Achievement

- Surface roughness and texture parameters of corn stover with variable degrees of microbial degradation were calculated directly from micrographs
- Surface energy and porosity were measured by inverse gas chromatography
- The results show variations and differing trends in the impact of biological degradation depending on the specific corn stover tissue type that was analyzed

Relevance

- Fundamental understanding of surface properties, and their variations across anatomical and tissue scales, informs development of advanced fractionation technologies to improve feedstock handling and tune pretreatment chemistries to plant fractions with variable, multi-scale factors of recalcitrance

Micro-scale mechanistic insights into macro-scale mechanical properties

Knowledge

Subtle changes in lignin structure were discovered that may underlie the increased brittleness of degraded biomass

Current Knowledge Gap

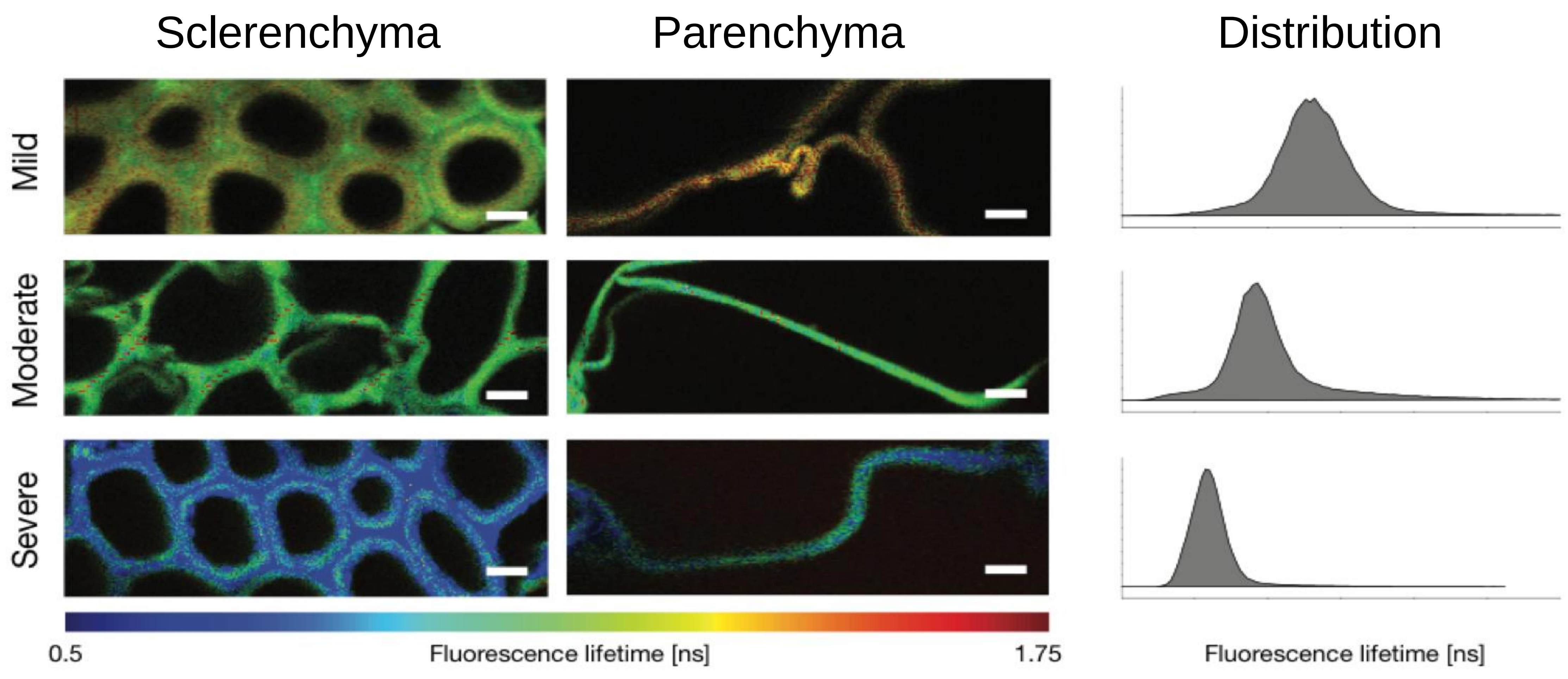
- We believe the changes in the structure and functional groups in the wall polymers could explain the physical property changes

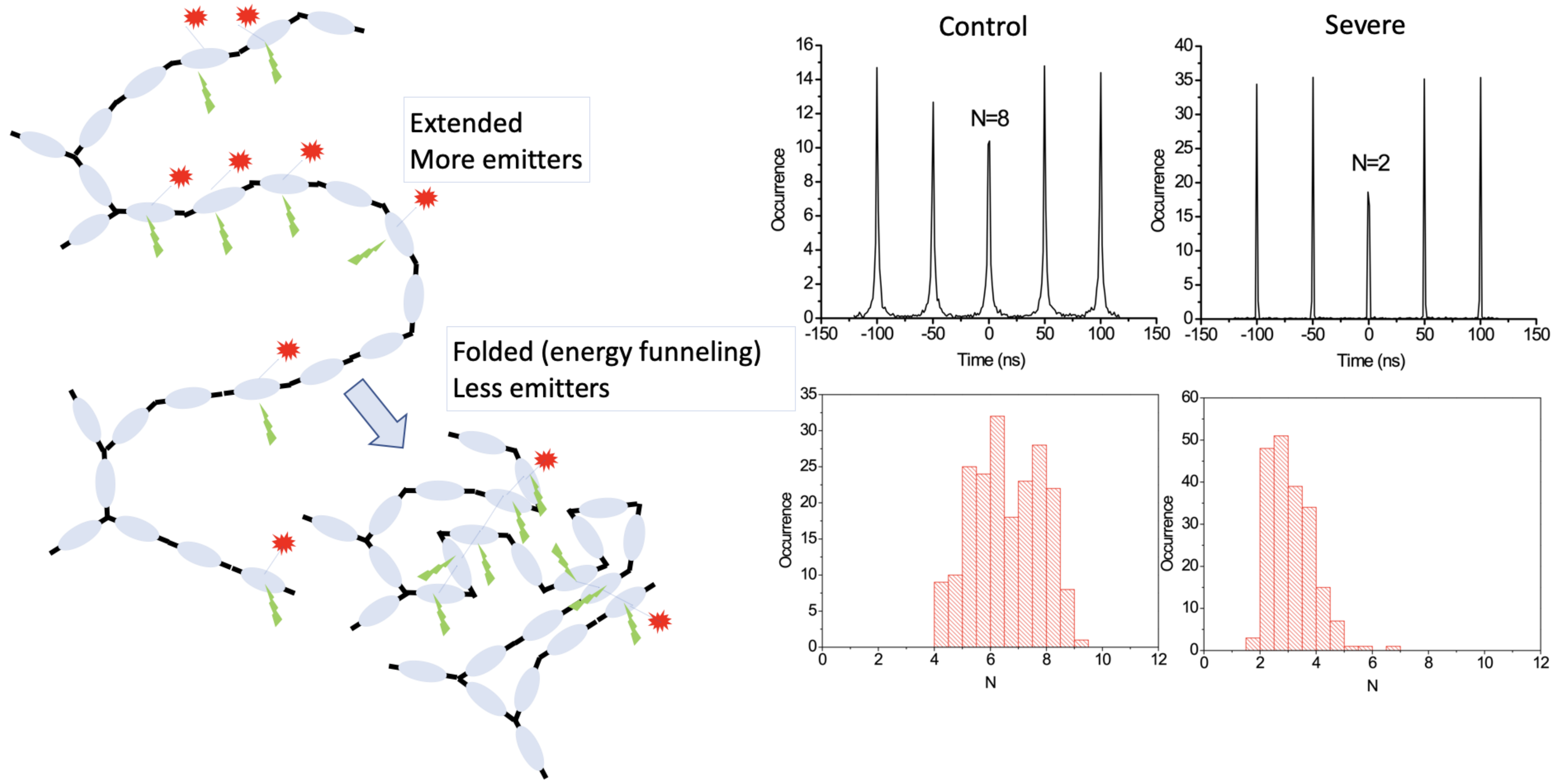
Achievement

- Shortening fluorescence lifetime correlated to the severity of biological heating, suggesting changes in lignin structure and environment
- If lignin coalescence and condensation is taking place, microfibrils will be restricted from rearrangement and result in a less elastic material

Relevance

- Modifications to structure and functional groups in cell wall biopolymers have implications for mechanical and chemical processing





Y. Zeng, A.N. Hoover, et al. Manuscript in Preparation

Analytic approaches provide insights to key sources of variability

Knowledge

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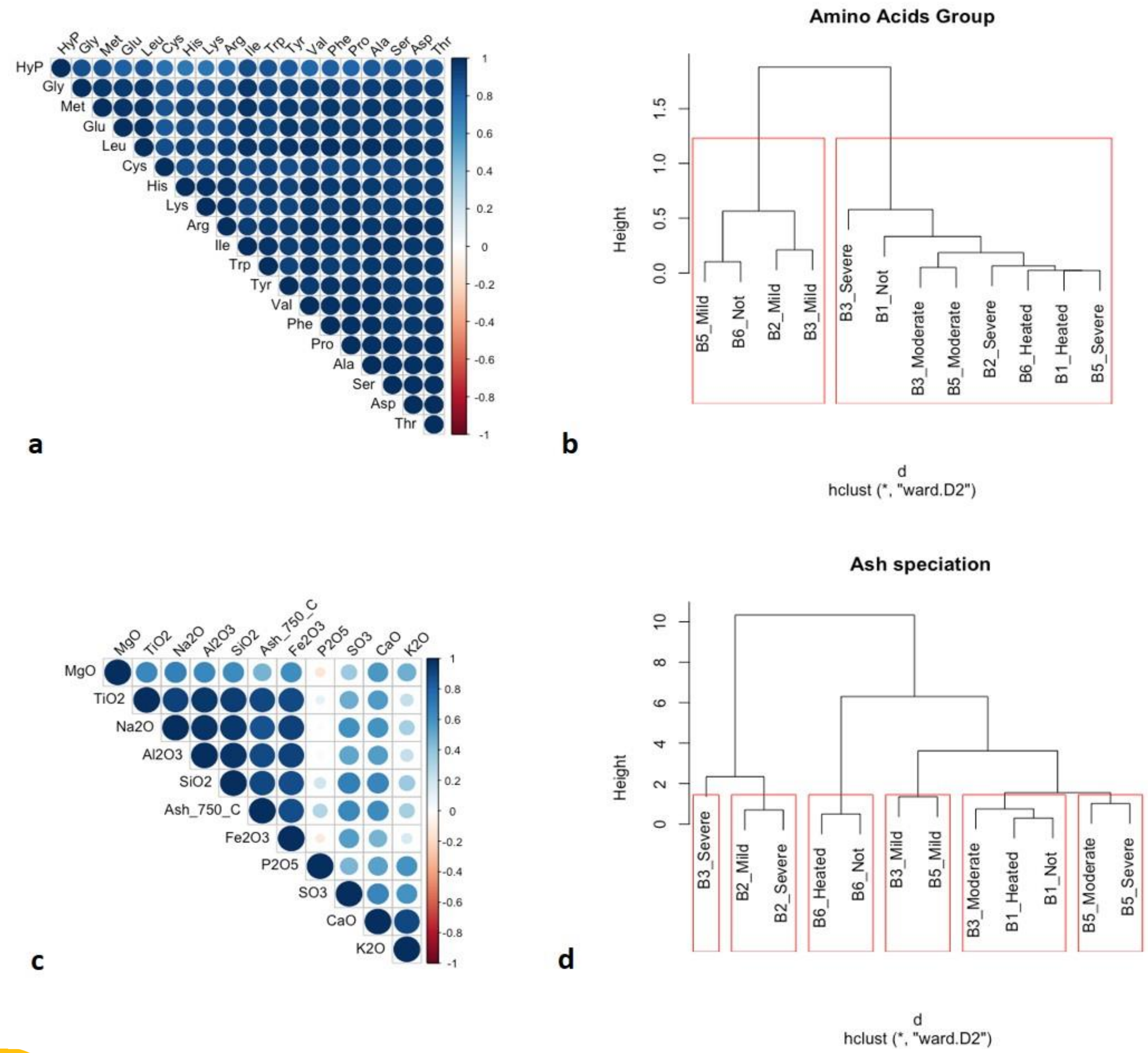
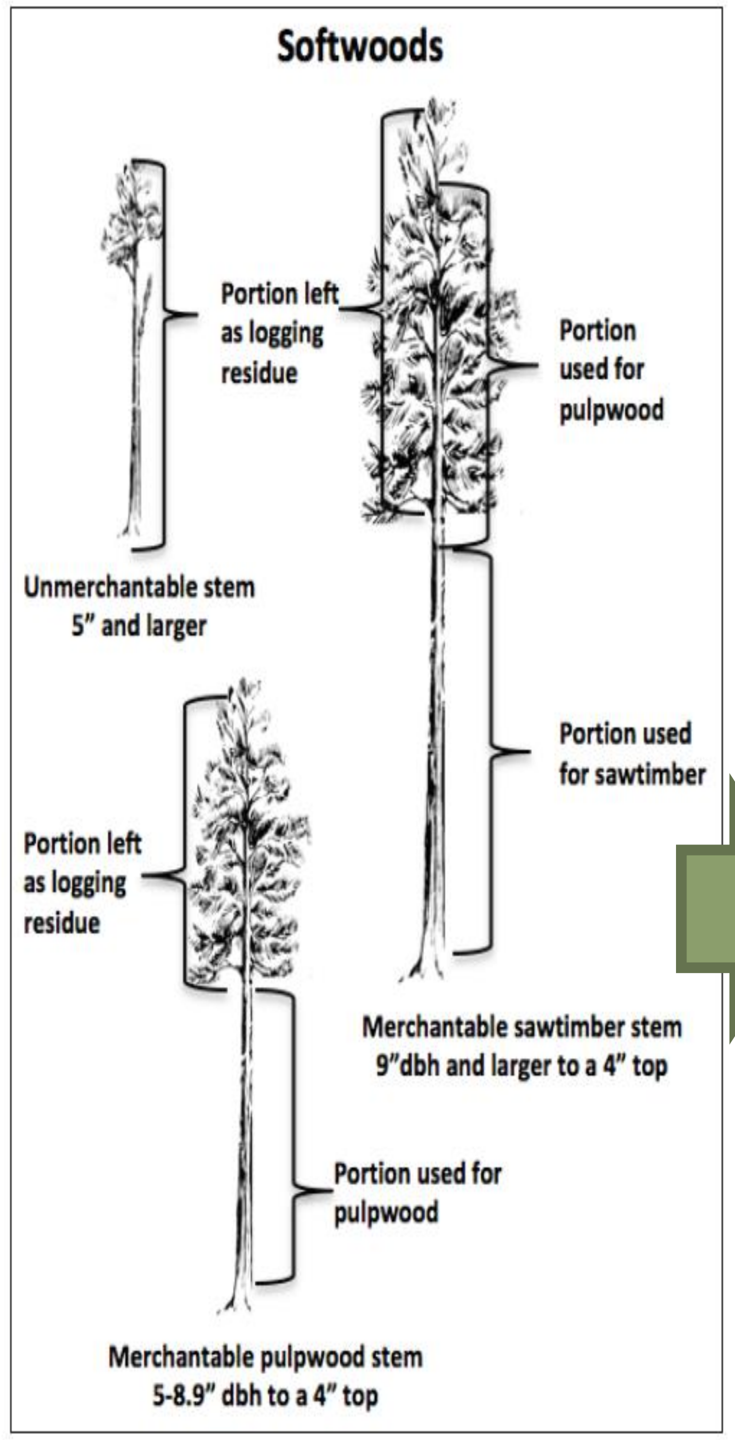
Data analytics can be used to glean key insights about sources of variability that affect biomass quality

- Correlation matrices and hierarchical clustering of compositional components
- Insights to key sources of variability
- Amino acid profiles in degraded stover (a) revealed that samples clustered as a function of extent of biological degradation (exception, bale 1 (b))
- Inorganic species in degraded samples (c) revealed a connection to harvest, mapping back to the original bales (exception, bale 3 (d))



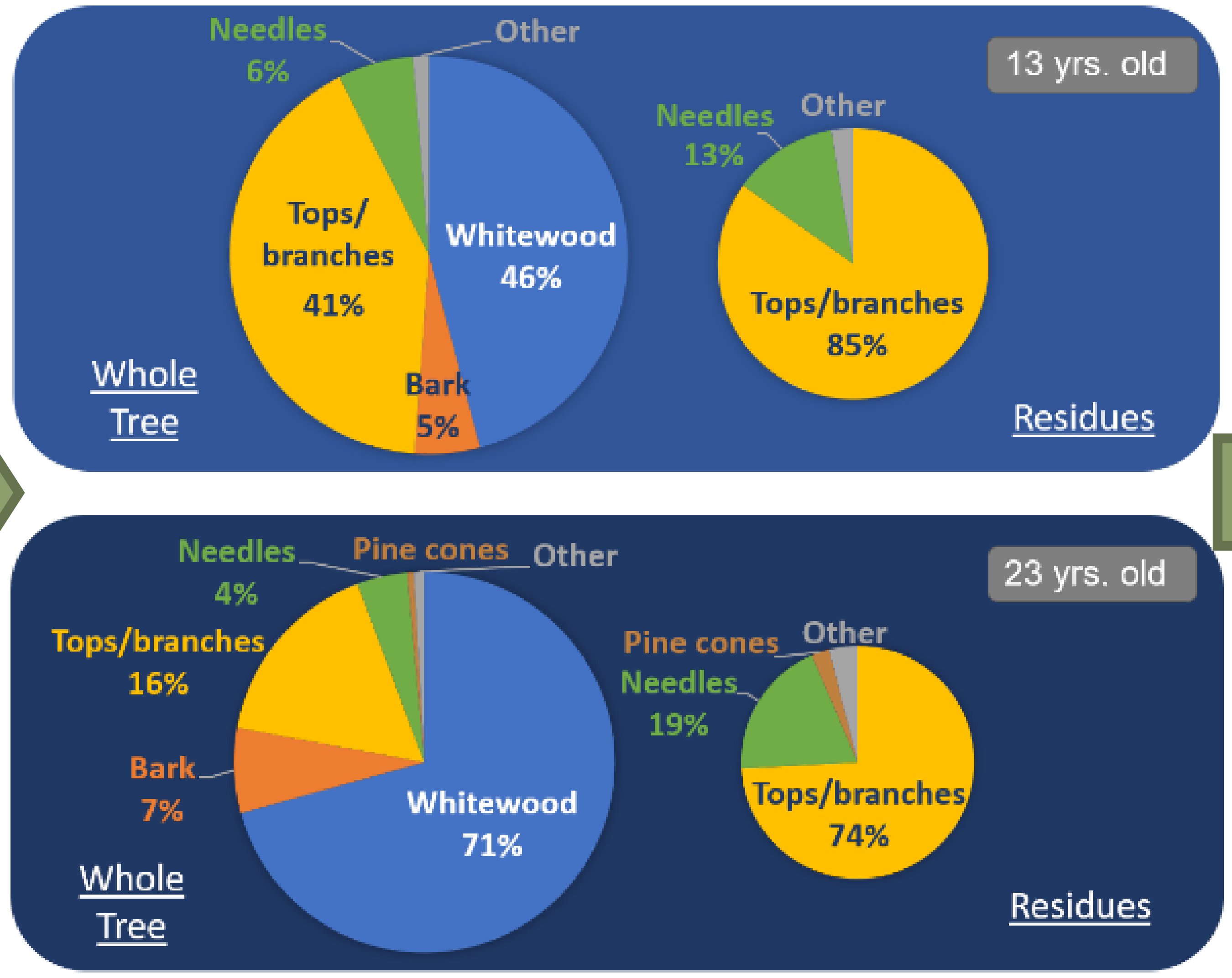
Case Study to Demonstrate Utility

FY21 Case Study of Interest and Associated Connections



(Bardon and Hazel, 2014)

Task 2: Feedstock Variability
Feedstock data on 13-yr vs 23-yr tree



Task 5: Pre-Processing
Data on distribution of feedstock CMAs

Task 6: High Temp Conversion
Translation of CMAs to CQAs in unit op

Pre-Processing

- **Physical Characteristics**
- **Chemical Speciation**
- **Aerodynamic Properties**
- **Other Properties**

Fast Pyrolysis → **Downstream Upgrading**

ChemCatBio
Chemical Catalysis for Bioenergy

Task 8: Crosscutting Analysis
TEA and LCA (with data input along process)

TD-NMR relaxometry reveals water distribution in anatomical fractions

Knowledge

Understanding the influence of local environments in porous materials on how water interacts with biomass

Current Knowledge Gap

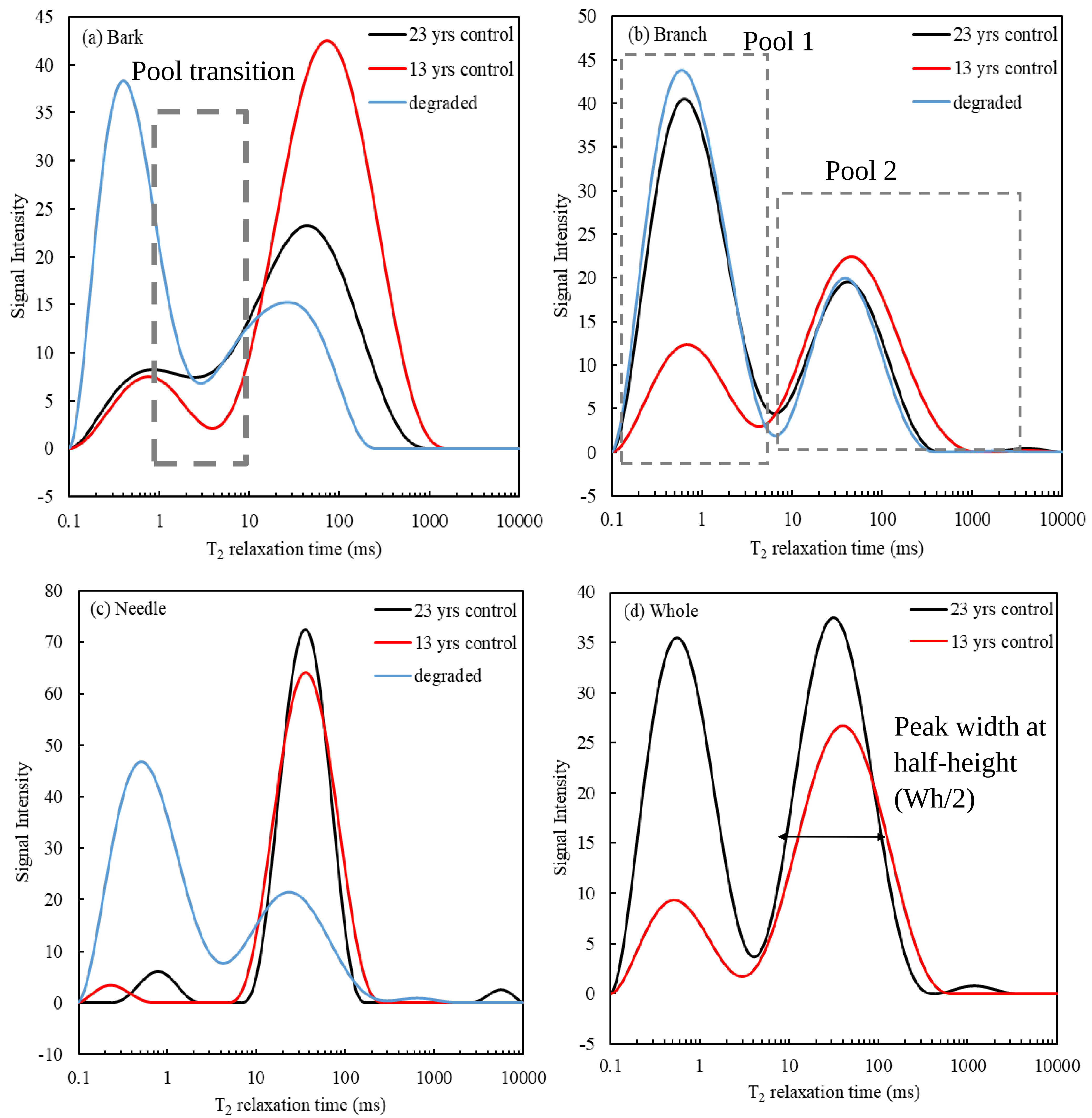
- Water status, distribution, and interactions with micro-structure influence physical and chemical changes during storage and preprocessing

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 fraction samples of corn stover and pine residues

Relevance

- Provides insights to understand and manage feedstock variability as well as informing harvest and storage best practices
- Informs development of advanced fractionation technologies



L. Ding, C. Li, A.E. Ray, et al. Manuscript in Preparation

Nanomechanical mapping of pine tissue fractions

Knowledge

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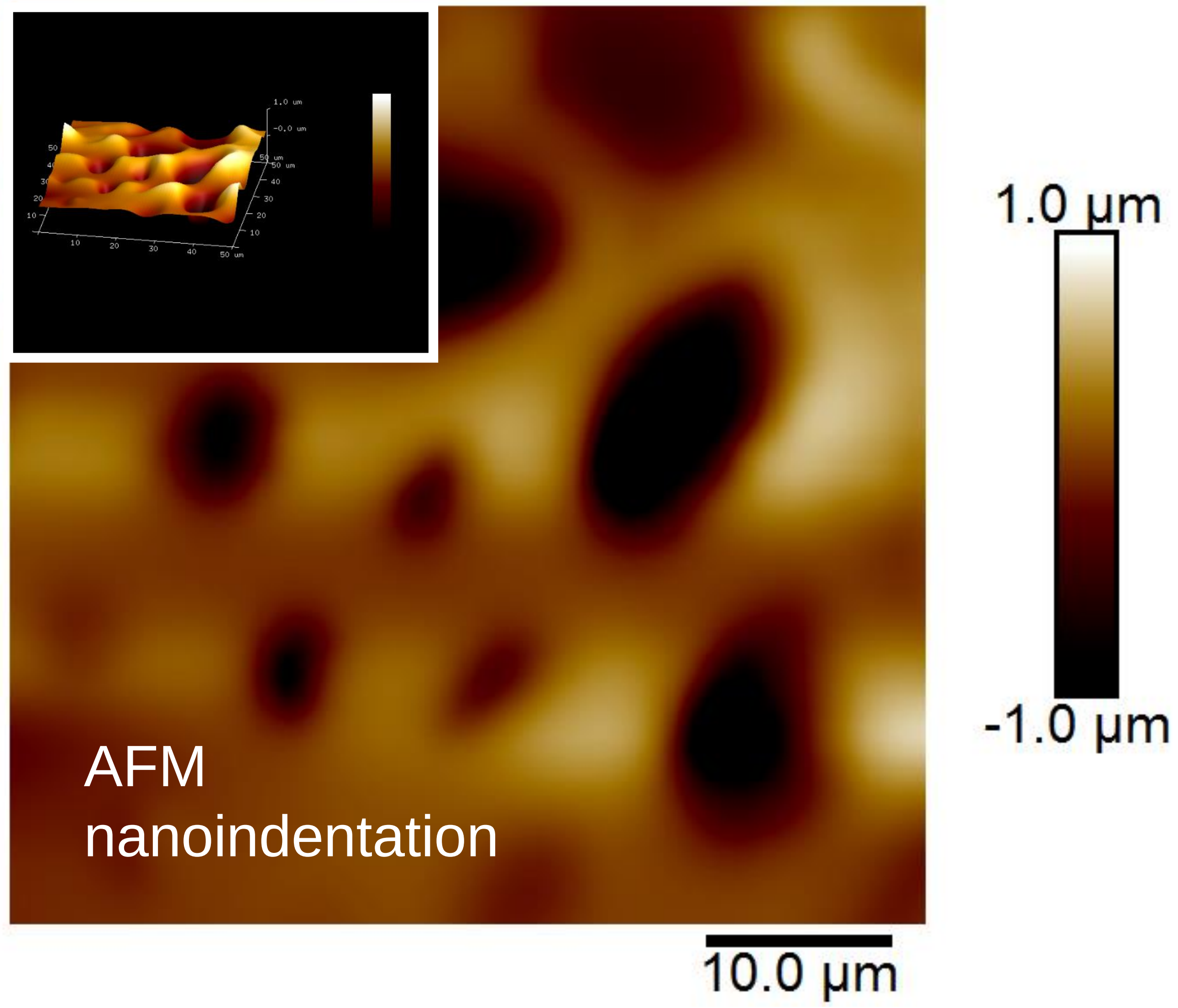
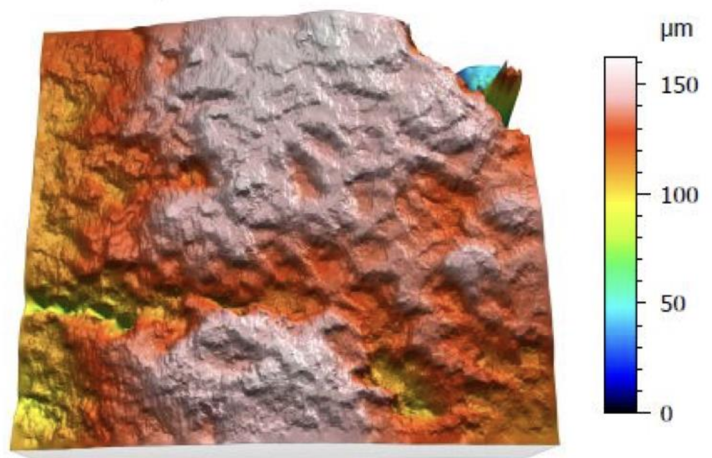
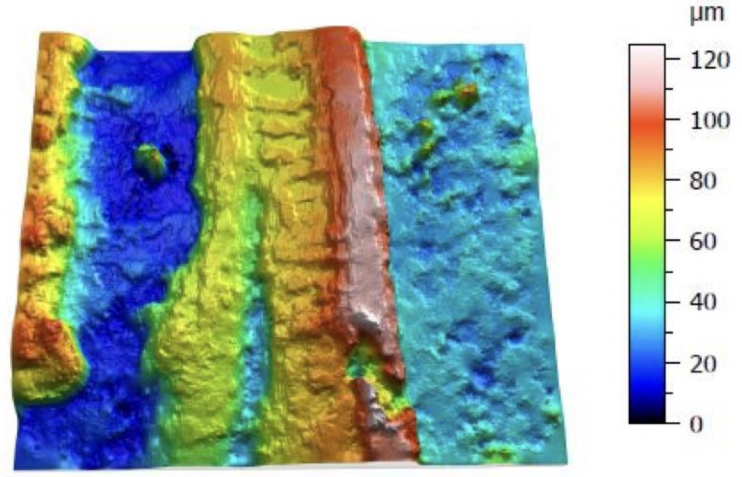
Test hypothesis that pine tissue fractions differ substantially in nanomechanical properties thought to impact materials handling and preprocessing



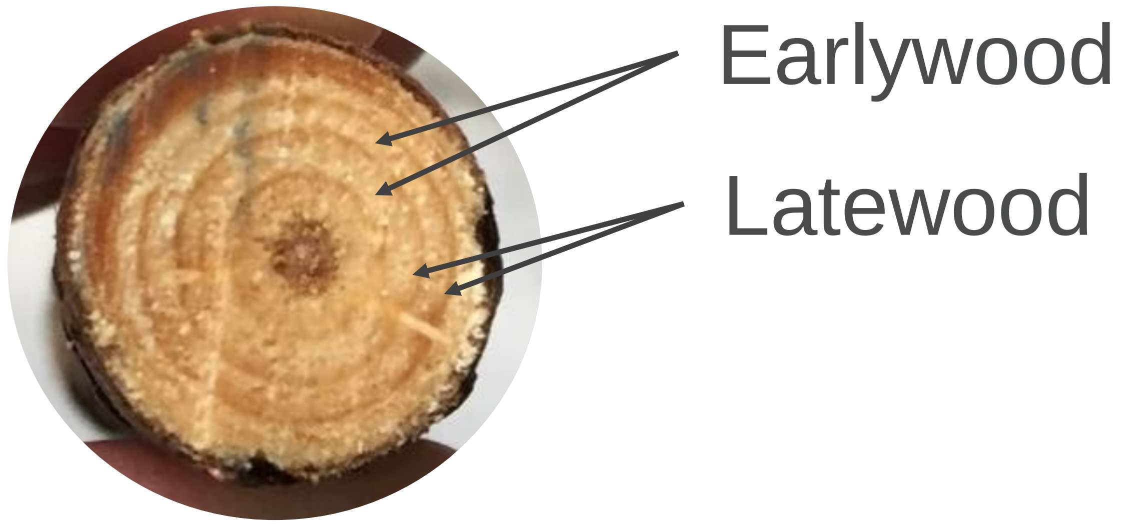




surface roughness
bark (left),
needle (right)

Current Knowledge Gap

- In progress quantitative nanomechanical mapping of loblolly pine tissue fractions from a 13 yr. old tree and a 23 yr. old tree
- Elastic modulus mapping of (1) needles, (2) early and latewood from branches and (3) bark from branches



Achievement

- Fundamental nanomechanical attributes support examination of how multiscale attributes in pine and stover anatomical fractions impact behavior in preprocessing and conversion

Relevance

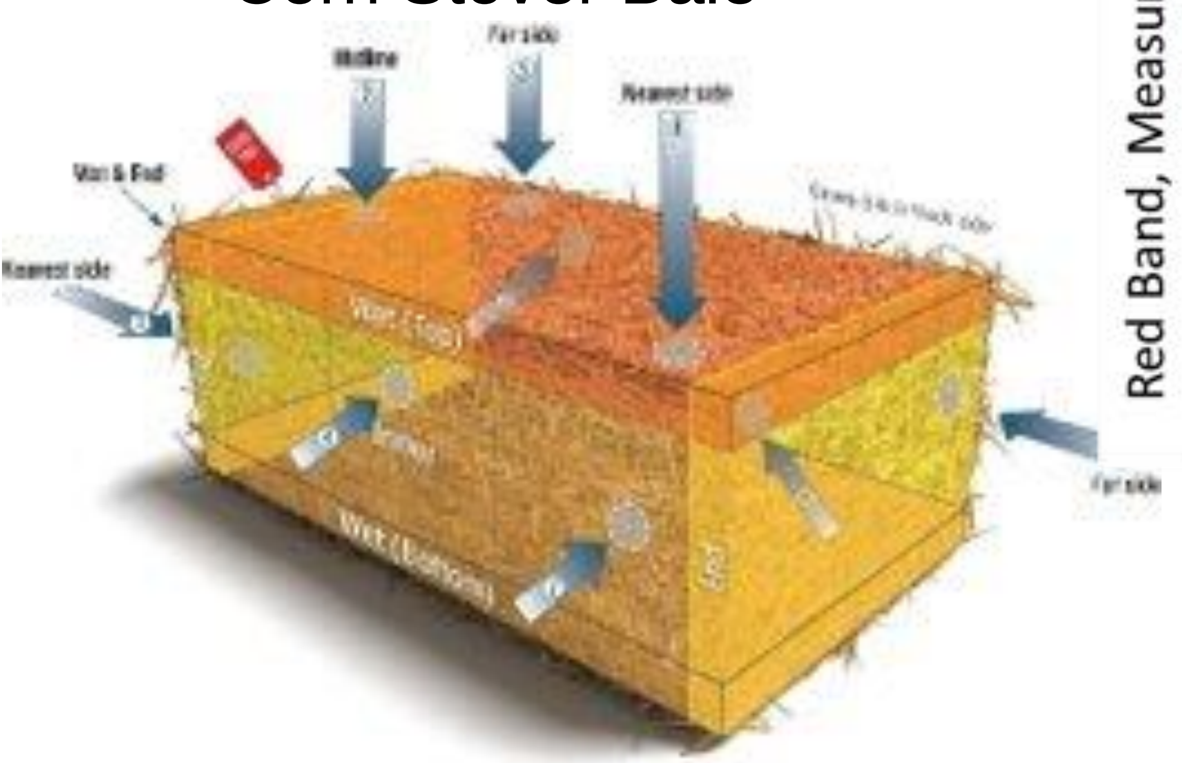
- Knowledge of the effects of intrinsic/supply chain factors on biomass physical/mechanical material attributes and their impacts downstream can inform harvest and collection best management practices and biorefinery risk management on the origins of biomass variability and how the variability may be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

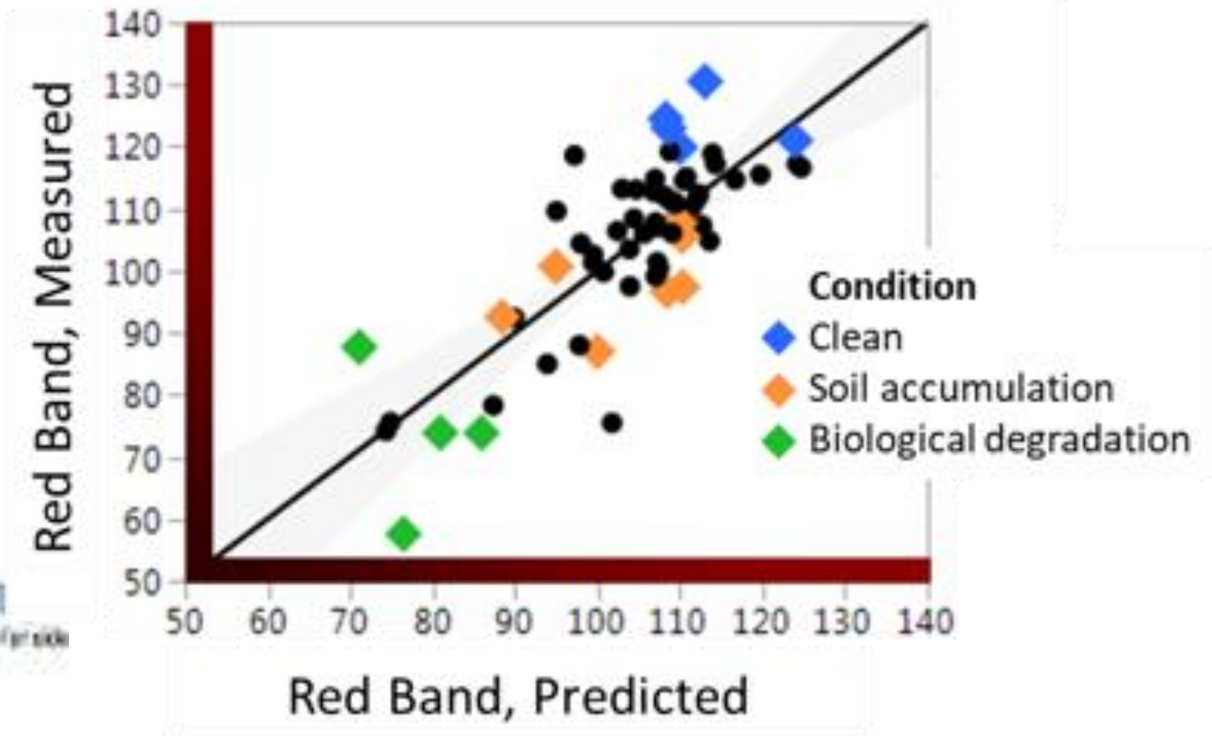
Image analysis of biomass: quality assessment in RGB color space

Tools

Image analysis for rapid assessment and sorting of corn stover/pine based on material attributes, and implications to preprocessing and conversion

Corn Stover Bale





Description

- Analysis of bale core images differentiates sample quality of soil-contaminated, biological degradation, and clean material
- 72% variability in red band explained by SiO_2 and glucan content
- In progress work to analyze broader FCIC soil contaminated and biologically degraded corn stover sample sets
- Future work to assess pine tissue fractions and contamination
- Images to augment datasets and/or develop calibration transfers to support subtask 5.5 machine vision for quality identification

Value of new tool

Enables process control/optimization by providing foundational information for sorting corn stover/pine based on material attributes

Potential Customers & Outreach Plan

Promise for development of a rapid screening tool that could be deployed by farmers for in-field assessment or by operators for in-line process measurement and downstream controls/optimization

Multiscale Characterization of Lignocellulosic Biomass Variability and Its Implications to Preprocessing and Conversion: a Case Study for Corn Stover
A.E. Ray, C.L. Williams, A.N. Hoover, C. Li, K.L. Sale, R.M. Emerson, J. Klinger, E. Oksen, A. Narani, J. Yan, C.M. Beavers, D. Tanjore, M. Yunes, E. Bose, J.H. Leal, J.L. Bowen, E.J. Wolfrum, M.G. Resch, T.A. Semelsberger, and B.S. Donohoe
ACS Sustainable Chemistry & Engineering 2020 8 (8), 3218-3230, DOI: 10.1021/acssuschemeng.9b06763

Summary

Management:

- Promote an open, collaborative team culture with multiple small meetings focused on common milestones

Technical Approach:

- Multiscale characterization to identify, quantify, and understand biomass feedstock CMAs with subtasks focused on understanding how the structural and physicochemical attributes of cell wall architecture and biomass tissue structure underlie flow behavior and the mechanical and thermochemical deconstruction of biomass

Impact:

- Providing characterization tools and CMA variability data that informs 1) storage and harvest best practices, 2) feedstock quality evaluation, and 3) selection of process configurations manage variability from field through conversion

Progress:

- Identified and disseminated knowledge about the importance and potential application of ~50 attributes of feedstock variability that can be used to evaluate feedstock quality and mitigate biorefinery disruptions

Quad Chart Overview- FCIC, Task 2

Timeline

- 10/1/2018 - 9/30/2021

	FY20	Active Project
DOE Funding	$ 1,785K	FY19- $ 2,100K FY20- $ 1,785K FY21- $ 1,885K Total- $ 5,770K

Project Partners (N/A)

Barriers addressed

Defining Metrics around Feedstock Quality

Feedstock Quality: Monitoring and Impact on Preprocessing and Conversion Performance

Biomass Storage Systems

Biomass Physical State Alteration

Project Goal

Develop tools to identify and quantify feedstock critical material attributes and inform strategies to reduce and manage the range and source of feedstock variability

End of Project Milestone

Quantify distributions of CMAs that inform operational envelopes and enable TEA/LCA, including inorganic species, moisture, extractives, lignin, hemicellulose, surface energy, surface roughness, & breaking strength for both HT and LT conversion, including discussion of criticality determination

Candidate CMAs for LT conversion include inorganic species, moisture, extractives, lignin, hemicellulose, surface energy, surface roughness, and breaking strength

Candidate CMAs for HT conversion include inorganic species, moisture, volatiles, lignin, hemicellulose, microstructure, and compressibility

Funding Mechanism (N/A)

Thank you

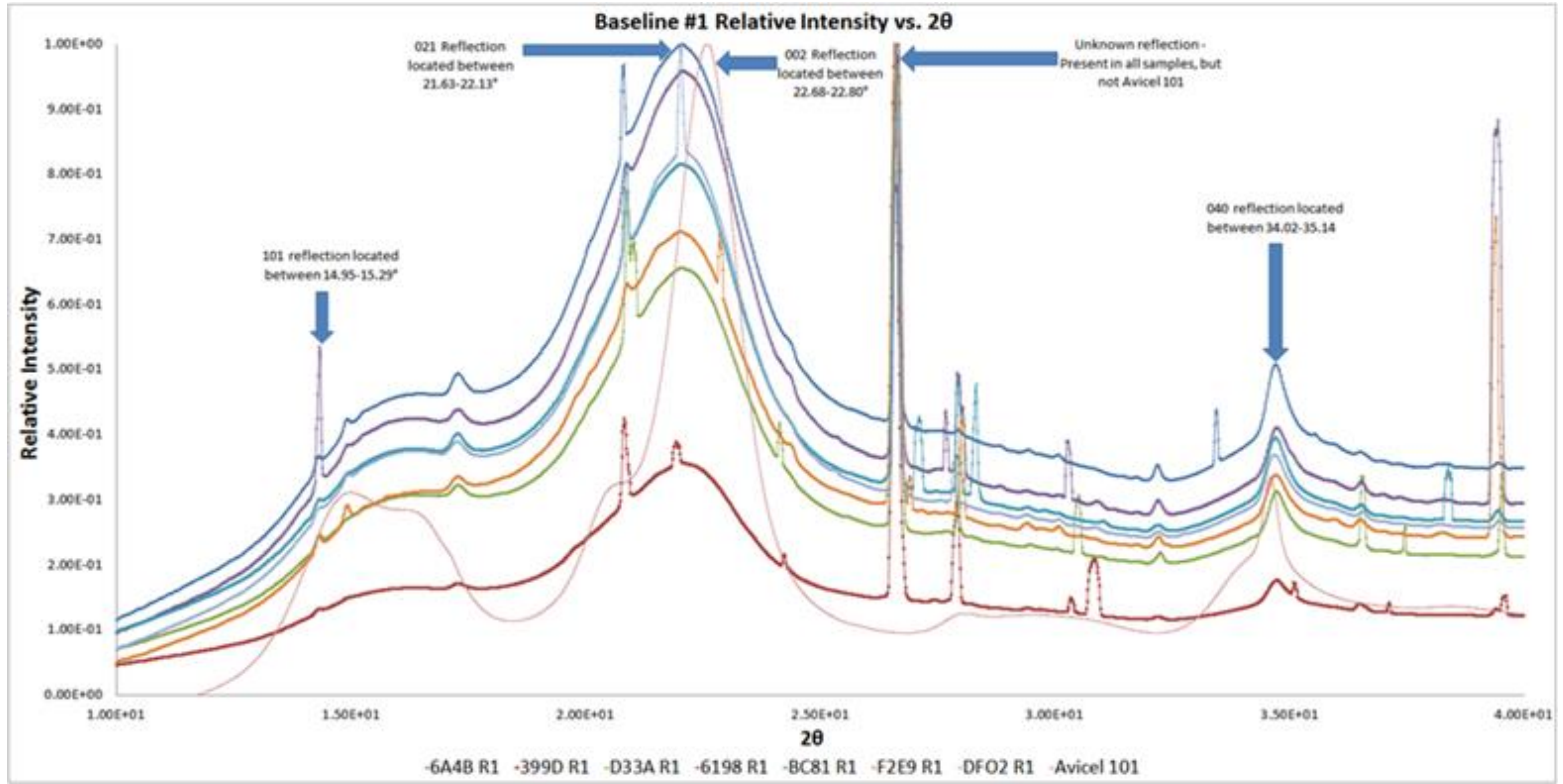
energy.gov/fcic

fcic
FEEDSTOCK-CONVERSION INTERFACE CONSORTIUM

Additional Slides

Leveraging DOE User & Collaboration Facilities

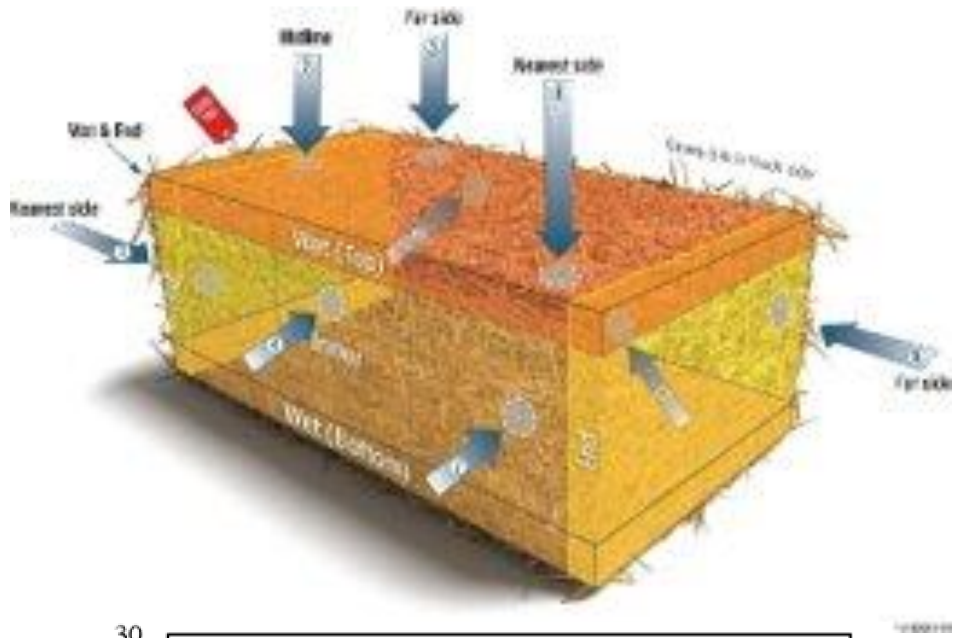
ADVANCED LIGHT SOURCE

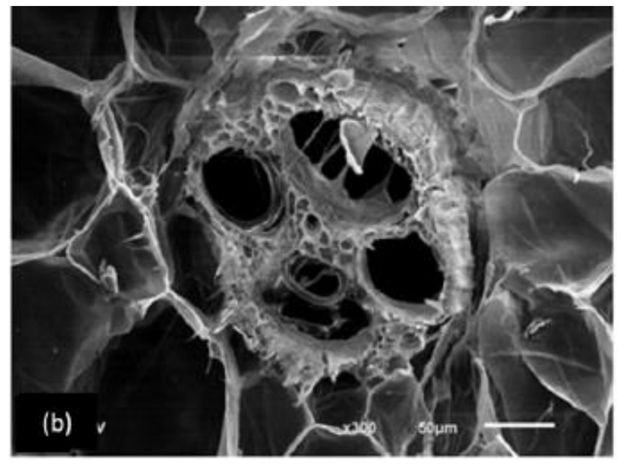


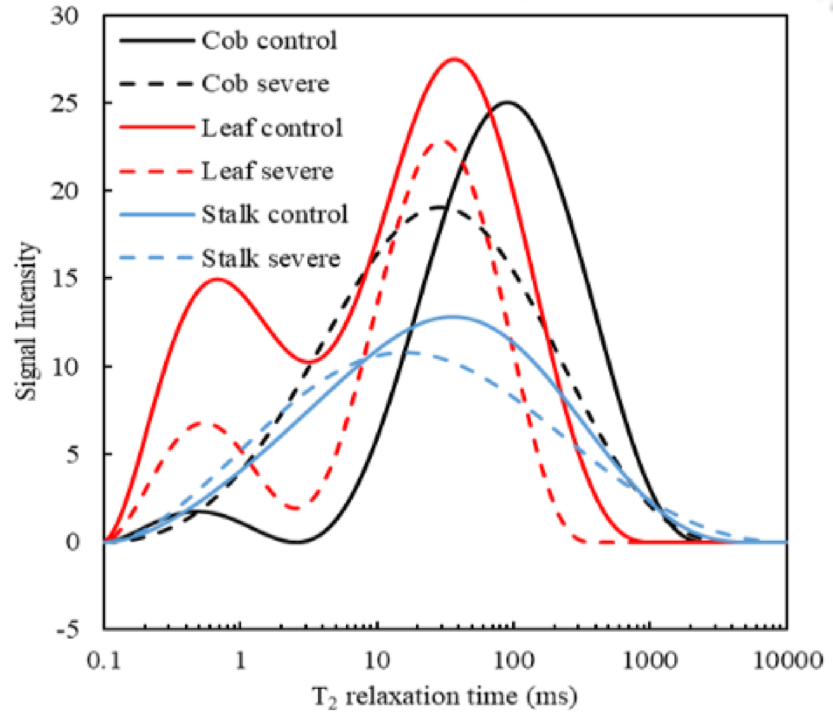
XRD diffraction studies at ALS

Advantage: Higher brightness & flux; faster data collection; continuous spectrum of wavelength going from infrared to the hard X-ray regime; tunable wavelength and monochromators

BIOMASS FEEDSTOCK NATIONAL USER FACILITY







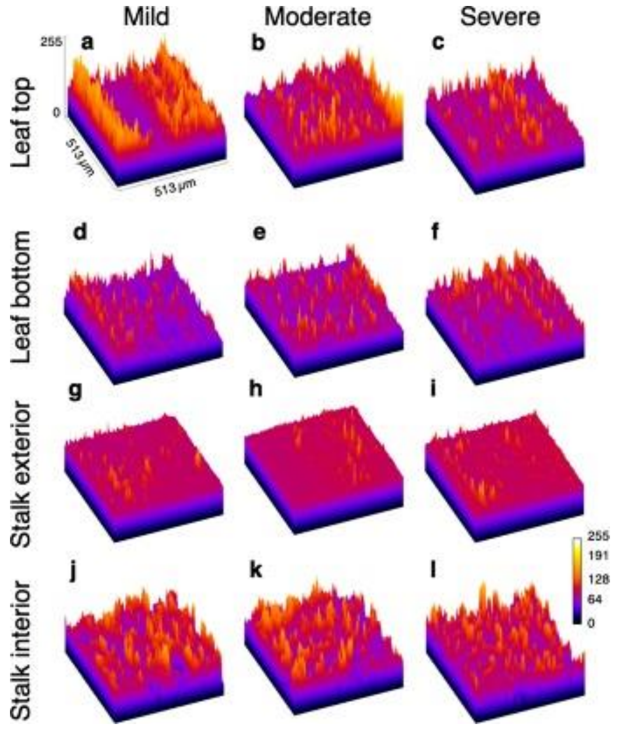
Advantage: Feedstock logistics R&D center with equipment from lab to pilot scale for multiscale characterization and preprocessing

ABPDU

Early-stage advanced biofuels, biomaterials, and biochemicals product and process technologies

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Biomass Surface Characterization Laboratory



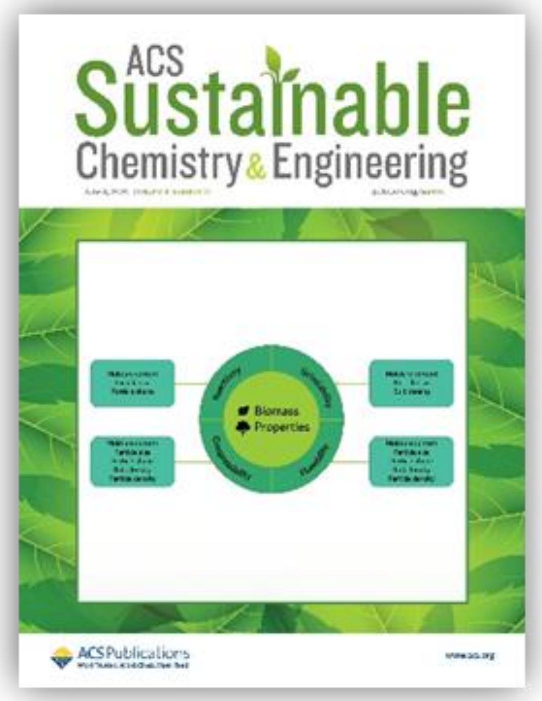
Responses to Previous Reviewers' Comments

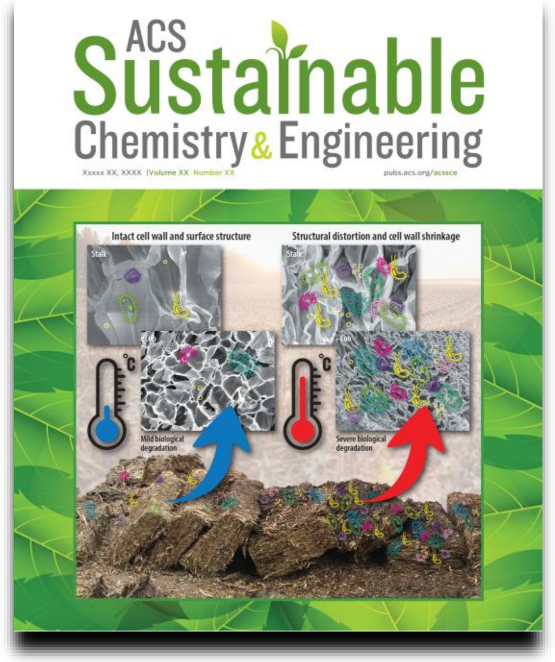
- Comment: *Project was not able to look at aging with regards to feedstock which is affected by moisture. Moisture and aging affects need to be separated. Whole log chips and branches plus needles have different chemical makeups and should not have been treated as the same feedstock even if the ash is different and it comes from the same tree.*
- **Response:** Partially in recognition of this limitation from the FCIC FY18 Baseline studies, we have chosen to focus our FY19 efforts on the topic of aging. In FY19-FY21, this project aims to quantify and understand the magnitude and range of physicochemical properties and material attributes for important sources of variability that impact the quality of available biomass resources. Sources of variability that will be investigated include aging/degradation in storage (FY19), anatomical fractions and harvest method (FY20), and environmental factors like precipitation, geographic location and soil chemistry (FY21).
- Comment: *I believe there should be more attention paid to addressing and or identifying potential risks and ways to mitigate these risks. For example, there was explanation of the effects of moisture on grinder efficiency with further statement that moisture is not the only factor affecting efficiency but no data or opinion on what these other factors may be or an approach to discover what these factors may or may not be. The project falls short in defining and identifying what makes for technical and or commercial viability. It states this but there is no data to help quantify what commercial and or technical viability is.*
- **Response:** We agree with the reviewer's comment that risk identification and mitigation and quality management are critical to de-risking the bioenergy industry and are also viewed as critical outcomes for the FCIC. This project provides data on the range of variability in key properties of corn stover and pine residues for an example supply shed from the FY18 experimental baseline runs. While we agree that this project was limited in its investigation of factors, we recognize that moisture impacts elasticity with implications for particle breakage and mechanical deconstruction in downstream operations. Discriminating between surface/free water versus bound water also enables understanding of particle cohesion and wettability, which affect flow behavior, material handling, and microstructure environments that dictate enzyme-substrate interactions critical to conversion. Under the revised structure for this project in the FY19 FCIC 2.0, we will perform fundamental and controlled studies and employ a multi-scale approach to elucidate mechanisms by which source of variability, like moisture, aging, and anatomical fractions, impact feeding, preprocessing, and conversion operation.

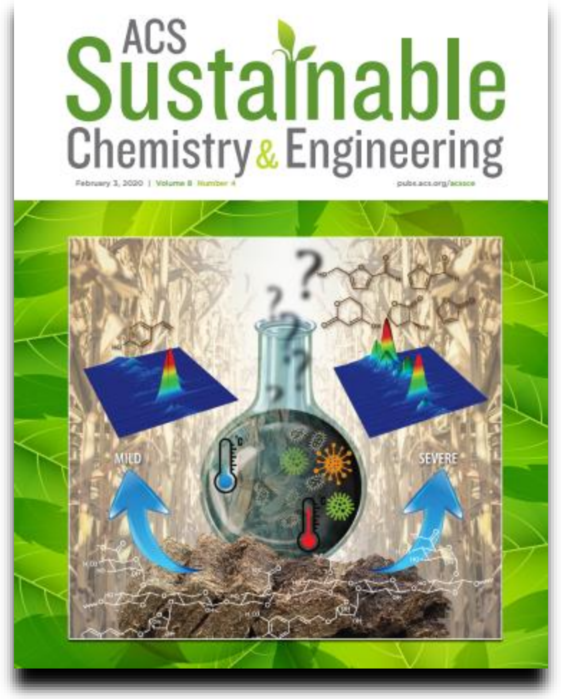
Publications, Patents, Presentations, Awards, and Commercialization

Publications:

- E. Bose, J.H. Leal, A.N. Hoover, Y. Zeng, C. Li, A.E. Ray, T.A. Semelsberger*, and B.S. Donohoe*, Impacts of biological heating and degradation during bale storage on the surface properties of corn stover. *ACS Sus Chem Eng* 2020, 8 (37), 13973-13983. DOI: 10.1021/acssuschemeng.0c03356
- Yan, J., Oyedeji, O., Leal, J., Donohoe, B., Semelsberger, T., Li, C., Hoover, A., Sun, N., Webb, E., Bose, E., Zeng, Y., Williams, C., Schaller, K., Ray, A.*, Tanjore, D*. Characterizing variability in lignocellulosic biomass - A review. *ACS Sus Chem Eng* 2020, 8 (22), 8059-8085. DOI: 10.1021/acssuschemeng.9b06263
- Ray, A.E.*, Williams, C., Hoover, A., Li, C., Sale, K., Emerson, R., Klinger, J., Oksen, E., Narani, A., Yan, J., Beavers, C., Tanjore, D., Yunes, M., Bose, E., Leal, J., Bowen, J., Wolfrum, E., Resch, M., Semelsberger, T., Donohoe, B*. Multi-scale characterization of lignocellulosic biomass variability and its implications to preprocessing and conversion —a case study for corn stover. *ACS Sus Chem Eng* 2020, 8 (8), 3218-3230. DOI: 10.1021/acssuschemeng.9b06763
- Li, C.***,** Kerner, P., Williams, C.L., Hoover, A., Ray, A.E.*. Characterization and Localization of Dynamic Cell Wall Structure and Inorganic Species Variability in Harvested and Stored Corn Stover Fractions as Functions of Biological Degradation. *ACS Sus Chem Eng* 2020, 8 (18), 6924-6934. DOI: 10.1021/acssuschemeng.9b06977
- G. Groenewold*, B. Hodges, A. Hoover, C. Li, C. Zarzana, K. Rigg, A.E. Ray*, Signatures of Biologically Driven Hemicellulose Modification Quantified by Analytical Pyrolysis Coupled with Multidimensional Gas Chromatography Mass Spectrometry, *ACS Sus Chem Eng 2020,* 8 (4), 1989-1997. DOI: 10.1021/acssuschemeng.9b06524 (Feb 3, 2020 issue with cover art)







Publications, Patents, Presentations, Awards, and Commercialization

Publications:

- Leal, J., Torres, E., Rouse, W., Moore, C., Sutton, A., Hoover, A., Li, C., Resch, M., Donohoe, B., Ray, A., Semelsberger, T*. Impacts of inorganic material (total ash) on surface energy, wettability & cohesion of corn stover. ACS Sus Chem Eng 2020, 8 (4), 2061-2072. DOI: 10.1021/acssuschemeng.9b06759
- Oyedeji, O.; Gitman, P.; Qu, J.; Webb, E., Understanding the Impact of Lignocellulosic Biomass Variability on the Size Reduction Process: A Review. ACS Sus Chem Eng 2020
- N.J. Nagle, B.S. Donohoe, E.J. Wolfrum, E.J. Kuhn, T.J. Haas, A.E. Ray, L.M. Wendt, M.E. Delwiche, N.D. Weiss, and C. Radtke, Chemical and Structural Changes in Corn Stover After Ensiling: Influence on Bioconversion. *Front Bioeng Biotechnol* 2020, DOI: 10.3389/fbioe.2020.00739.
- Leal, J. H.; Moore, C. M.; Sutton, A. D.; Semelsberger, T. A. Surface energy of air fractionated corn stover. *Ind. Crops Prod.* 2019, 137, 628– 635, DOI: 10.1016/j.indcrop.2019.05.046
- Hess, J. R.*; Ray, A. E.*; Rials, T. G.*, Editorial: Advancements in Biomass Feedstock Preprocessing: Conversion Ready Feedstocks. *Front Energy Res* 2019, 7 (140). DOI: 10.3389/fenrg.2019.00140
- Hoover, A.; Emerson, R.; Williams, C. L.; Ramirez-Corredores, M.; Ray, A.; Schaller, K.; Hernandez, S.; Li, C.; Walton, M., Grading Herbaceous Biomass for Biorefineries: a Case Study Based on Chemical Composition and Biochemical Conversion. *BioEnergy Research* 2019, 12 (4), 977-991. DOI: 10.1007/s12155-019-10028-3

Publications, Patents, Presentations, Awards, and Commercialization

Presentations:

- Allison Ray. Unveiling Signatures of Biomass Variability. ACS Fall 2020 Virtual Meeting & Expo, August 17-20, 2020.
- Allison Ray. FCIC: Feedstock Variability. Advanced Bioeconomy Leadership Conference (ABLC); (Online, https://video.ibm.com/recorded/127312008) July 10, 2020.
- Troy Semelsberger and Carrie Hartford. Smart Transfer Chutes with In-Line Acoustic Sensors for Bulk Solids-Handling Solutions, in Innovative Sensing Technologies for Biomass and Feedstock Production and Logistics. Advanced Bioeconomy Leadership Conference (ABLC); (Online) July 10, 2020.
- Chenlin Li. Dynamic Cell Wall Structure and Composition Variability in Corn Stover Fractions as Functions of Biological Degradation—A Case Study of Feedstock Inherent and Introduced Variability. ASABE 2020 Annual International Meeting, July 13-15, 2020.
- Allison Ray and Bryon Donohoe. FCIC: Feedstock Variability, presented to Agile BioFoundry Consortium Team, July 1, 2020.
- Brittany D.M. Hodges, A.N. Hoover, C. Li, G.S. Groenewold, C.A. Zarzana, L.M. Wendt, K. Rigg, A.E. Ray. Biomass Comparison, Characterization, and Quantification with Analytical Pyrolysis GCxGC-MS. American Society for Mass Spectrometry 68th Annual Conference, (Online) June 1-19.
- Emerson, R., Rowland, S., Klinger, J., Carpenter, D., Pilgrim, C., Harman-Ware, A., Fillerup, E., Starace, A., Ray, A., Hoover, A., Thomas, B. Impacts of biopolymer structural and chemical attributes on the products distributions of pyrolyzed loblolly pine. TCS 2020 (Thermal & Catalytic Sciences). October 5-7, 2020.

Accepted Abstracts:

- Allison E. Ray, C. Luke Williams, Amber N. Hoover, Chenlin Li, Kenneth Sale2, Rachel M. Emerson, Jordan Klinger, Ethan Oksen, Akash Narani, Jipeng Yan, Christine Beavers, Deepti Tanjore, Manal Yunes, Elizabeth Bose, Juan H. Leal, Julie Bowen, Edward Wolfrum, Michael Resch, Troy A. Semelsberger and Bryon S. Donohoe, Multi-scale characterization of lignocellulosic biomass variability and its implications to preprocessing and conversion —a case study for corn stover. SIMB Abstract.
- Yining Zeng, Amber N. Hoover, Renee Happs, Elizabeth Bose, Allison E. Ray and Bryon S. Donohoe. Feedstock variability: changes in lignin caused by biological heating during bale storage. SIMB Abstract.
- Gary Groenewold, Brittany Hodges, Amber N. Hoover, Chenlin Li, Christopher Zarzana, Kyle Rigg and Allison E. Ray*. Signatures of biologically driven hemicellulose modification quantified by analytical pyrolysis coupled with multidimensional gas chromatography mass spectrometry. SIMB Abstract.
- Patricia Kerner, C. Luke Williams, Amber N. Hoover, Allison E. Ray and Chenlin Li. Characterization and Localization of Dynamic Cell Wall Structure and Inorganic Species Variability in Corn Stover Fractions as Functions of Biological Degradation in Storage. SIMB Abstract.
- Juan H. Leal, Estrella L. Torres, William T. Rouse, Cameron M. Moore, Andrew D. Sutton, Amber N. Hoover, Chenlin Li, Michael Resch, Bryon S. Donohoe, Allison E. Ray and Troy A. Semelsberger. Impacts of inorganic material (total ash) on surface energy, wettability & cohesion of corn stover. SIMB Abstract.

Publications, Patents, Presentations, Awards, and Commercialization

Awards:

- Allison Ray, 2019 *Frontiers* Spotlight Award Nominee & Guest Associate Editor, *Frontiers in Energy Research*, Advancements in Biomass Feedstock Preprocessing: Conversion-Ready Feedstocks (special issue ranked in the top 10 of 1000 *Frontiers* topics in 2019)

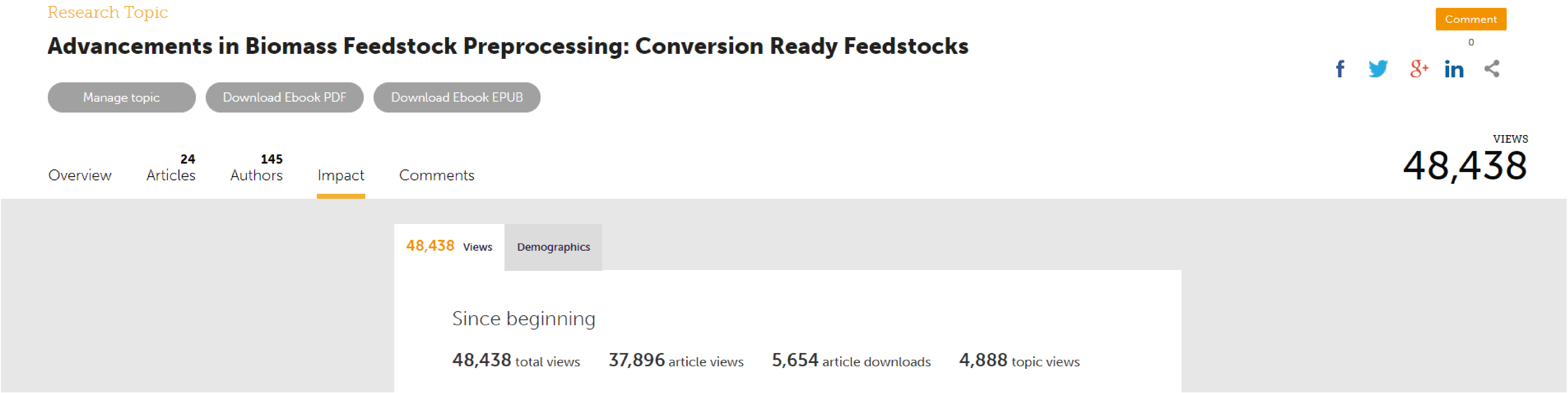
frontiers SPOTLIGHT

Economic eco-fuels

https://spotlight.frontiersin.org/economic-eco-fuels

Frontiers in Energy Research Special Issue—

A Spotlight Award 2019 Finalist



https://www.frontiersin.org/research-topics/7068/advancements-in-biomass-feedstock-preprocessing-conversion-ready-feedstocks