DOE Bioenergy Technologies Office (BETO) 2021 Project Peer Review

Enhanced Feedstock Characterization and Modeling to Facilitate Optimal Preprocessing and Deconstruction of Corn Stover

DE-EE0008907 FY19 BETO MultiTopic FOA

10 March, 2021
Feedstock Technology Program

David Hodge
Montana State University

Project Overview

- **Challenges**
  - Chemical and physical heterogeneity in herbaceous biomass feedstocks due to substantial differences in tissue types can contribute to challenges to handling, preprocessing, and conversion in biorefining processes
  - How to quantify this heterogeneity and potentially exploit these differences to facilitate more streamlined processing/preprocessing?

- **Project Approach**
  - Develop/adapt technologies for physical fractionation of corn stover
  - Develop/adapt new tools for characterization of fractionated corn stover

Project Overview

OBJECTIVE 1: Identify conditions for optimal fractionation using a two-stage physical fractionation

OBJECTIVE 2: Assess how physical fractionation impacts properties, partitioning of biomass, and response to processing

OBJECTIVE 3: Develop, and validate advanced characterization tools for assessing biomass properties

OBJECTIVE 4: Develop and validate predictive models based on measurements to relate chemical and physical properties to processing behavior (preprocessing and deconstruction)

TASK 1. Initial Verification
- Work with DOE verification team to define baseline technology readiness level

TASKS 2, 4. Physical Fractionation of Corn Stover
- Fractionation by cell type for model development
- Shredding-comminution coupled to fractionation by sieving, air classification

TASKS 3, 5. Characterization of Fraction Properties
- Chemical composition (polysaccharides, lignin, ash)
- Water-biomass interactions (WRV, TD-NMR)
- Distribution of particle size, morphology, cell types
- Response to pretreatment and enzymatic hydrolysis

TASK 6. Model Development and Validation
- Correlation of characterized properties
- Development of models to assess preprocessing performance and predict responses to deconstruction
- Model validation in a relevant environment

TASK 7. Project Management and Reporting
- Reporting submitted
- Participation in FY21 PEER Review

Project Overview

Corn Stover → Primary Fractionation → Stem-Rich Fraction → Secondary Fractionation

Primary Fractionation ↓

Other Fractions, *e.g.*:
- Leaves, leaf sheaths, and husks
- Cobs
- Fines and ash

Secondary Fractionation ↓

Other Fractions, *e.g.*:
- Nodes
- "Fibers"
- Rind
- Fines and ash

Pith-Rich Fraction

- Develop Novel Heterogeneity Reducing Fractionation Technologies for Corn Stover
- Understand Relationship Between Preprocessing Conditions and Fraction Properties

Idaho National Laboratory

Develop and Apply Novel Characterization Tools

Low-Field ^{1}H NMR Relaxometry
- Different pools of sorbed water

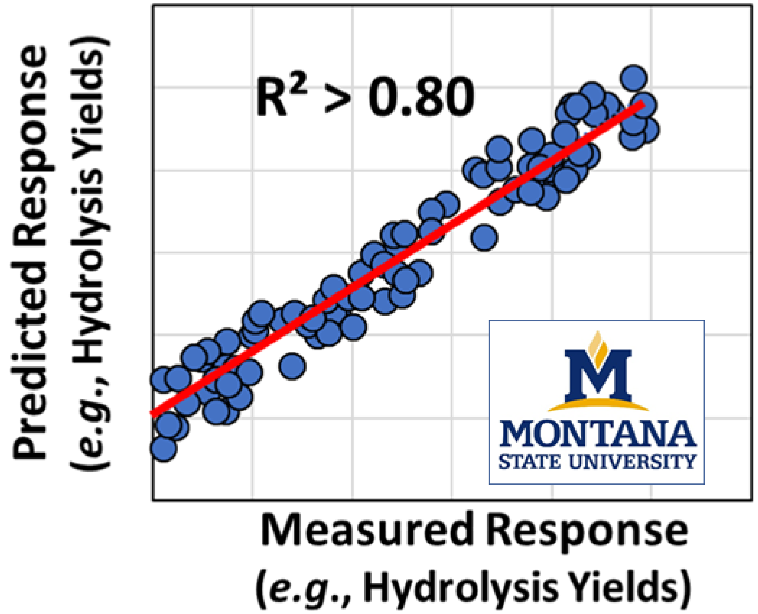
Water Retention Value
- Feedstock hygroscopicity

Dynamic Image Analysis
- Distributions of particle dimensions, classification of tissue types

MONTANA STATE UNIVERSITY

Develop and Validate Robust Models to Assess and Predict Processing Performance

- Preprocessing: Classification of Tissue Type
- Deconstruction: Prediction of Hydrolysis Yields



1 – Management

Project Team

- **Montana State University (lead)** → **Tasks 1, 3, 5** →
  - Characterization
  - Modeling

David Hodge (PI)

Joe Seymour

Chem. Eng. Grad Student 1:
- Will Otto – B.S. Michigan Tech. (Chemical Engineering)

Chem. Eng. Grad Student 2
- Matt Young – B.S. U. Jamestown (Chemistry)

Postdoctoral Researcher
- Dylan Cousins – Ph.D. Colorado School of Mines (Chemical Engineering)

- **Idaho National Laboratory**

Tasks 1, 2, 4 →
- Physical Fractionation

John Aston

Allison Ray

Jeff Lacey

Sergio Hernandez

1 – Management

Project Management and Implementation

- Weekly within institution meetings
- Monthly project meetings (all participants and BETO management)
- Student exchange with INL
- Identification of risks, challenges, and identification of alternative approaches

Integration with Related Projects

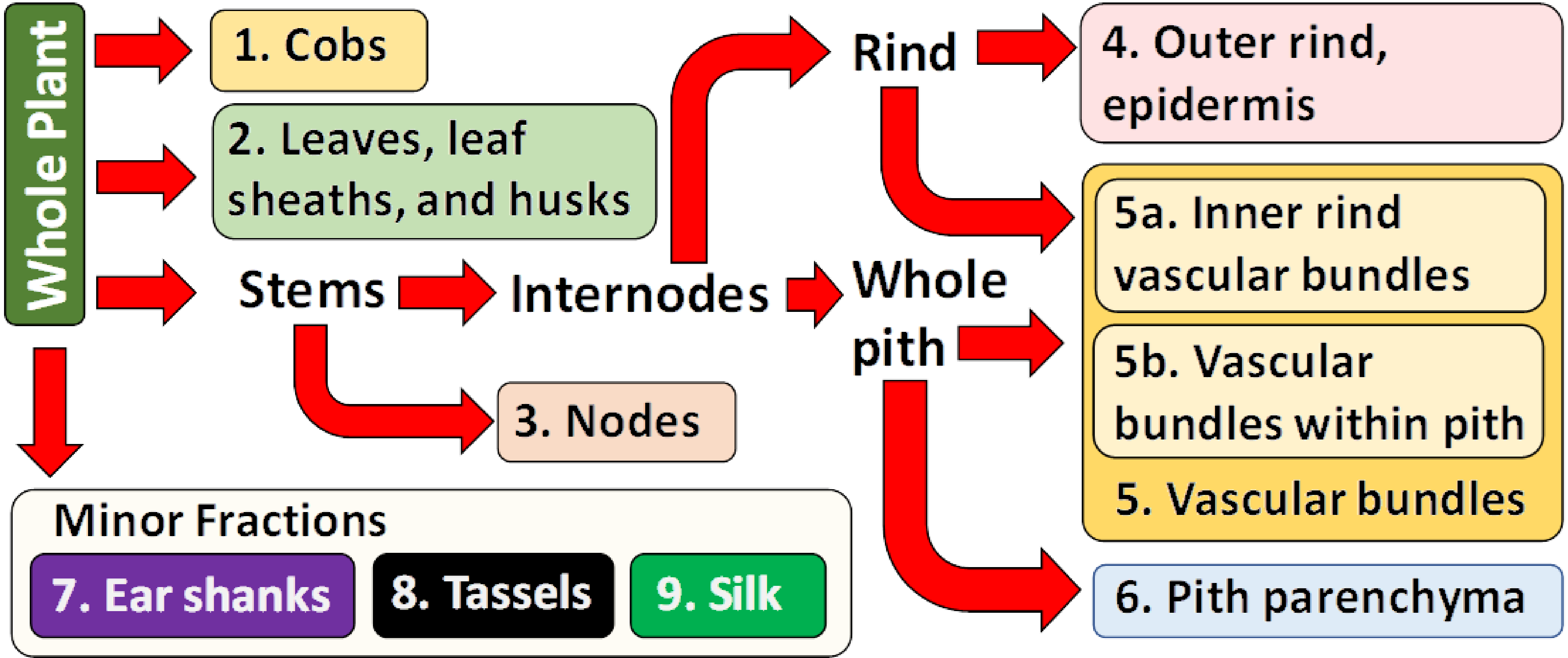
- Collaboration and leveraging ongoing work with Feedstock-Conversion Interface Consortium (FCIC) members

2 - Approach

- **Task 1**: Initial Verification
  - Work with DOE verification team to define baseline technology readiness level

Go/No-Go Decision Point DP 1.1
✓ Complete

- **Tasks 2, 4** : Physical Fractionation of Corn Stover
  - Fractionation by cell type as reference set for model development

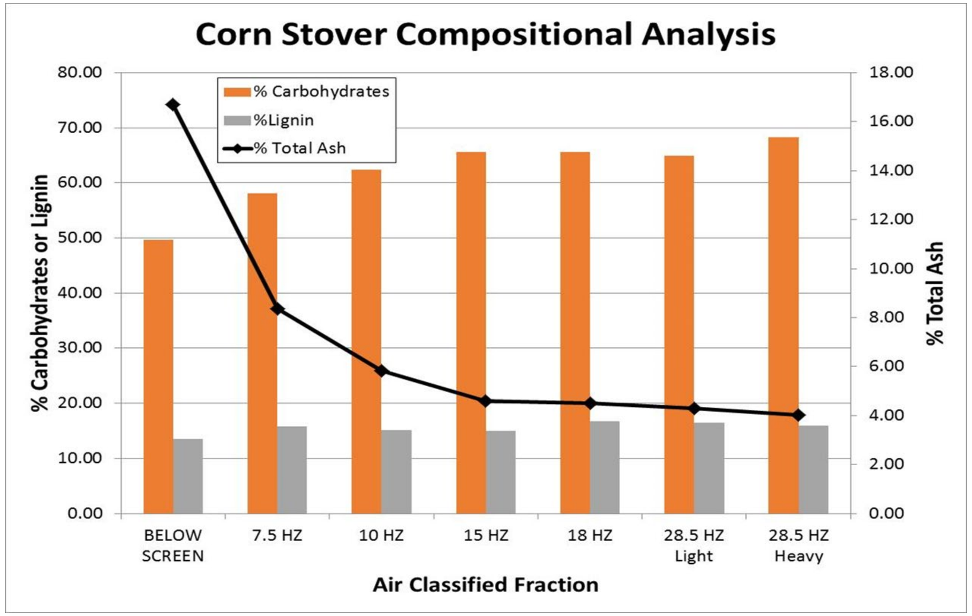


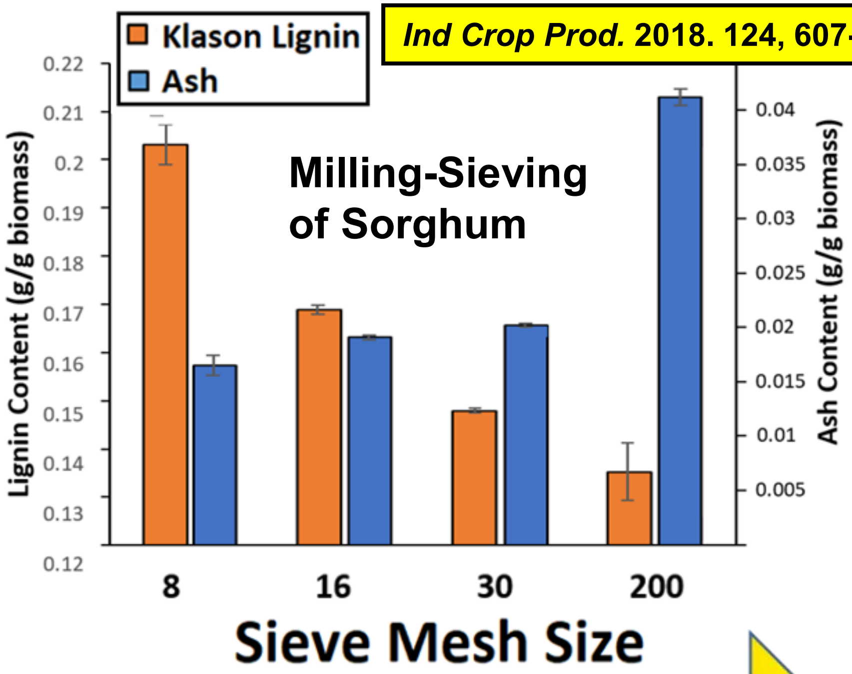
Milestone M2.1.1 : Manual Fractionation
✓ Complete

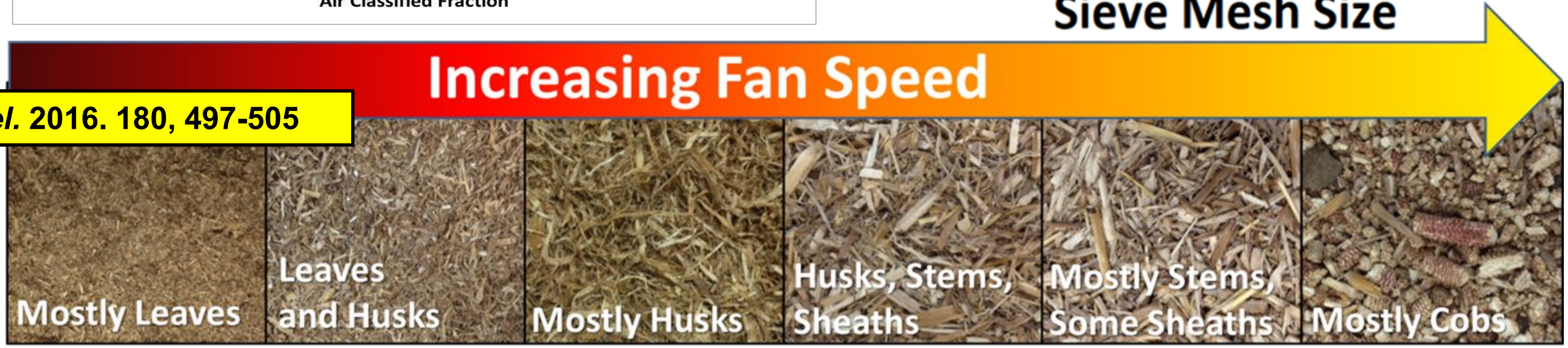
2 - Approach

- **Tasks 2, 4**: Physical Fractionation of Corn Stover
  - Shredding-comminution coupled to fractionation by sieving, air classification

Ind Crop Prod. 2018. 124, 607-616







Fuel. 2016. 180, 497-505

2 - Approach

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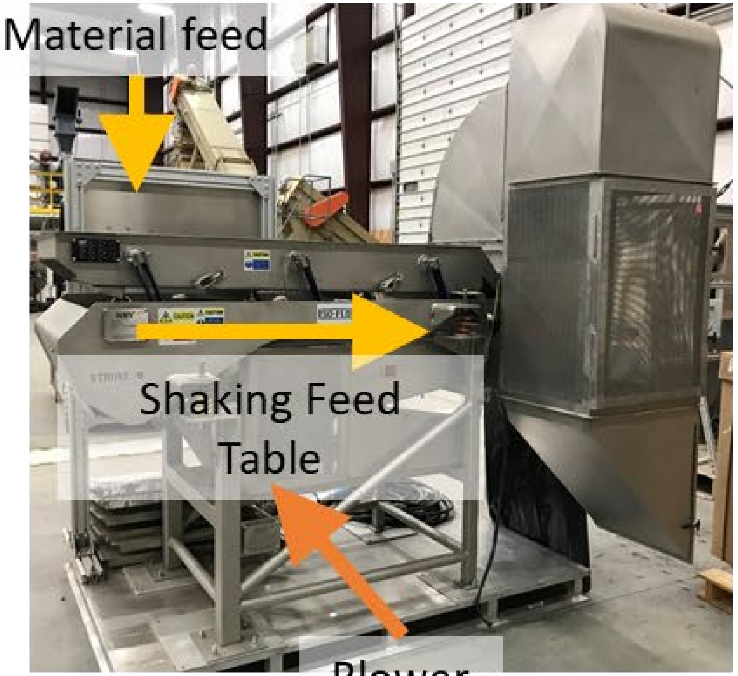


Model 2x Air Cleaner, Key Technologies

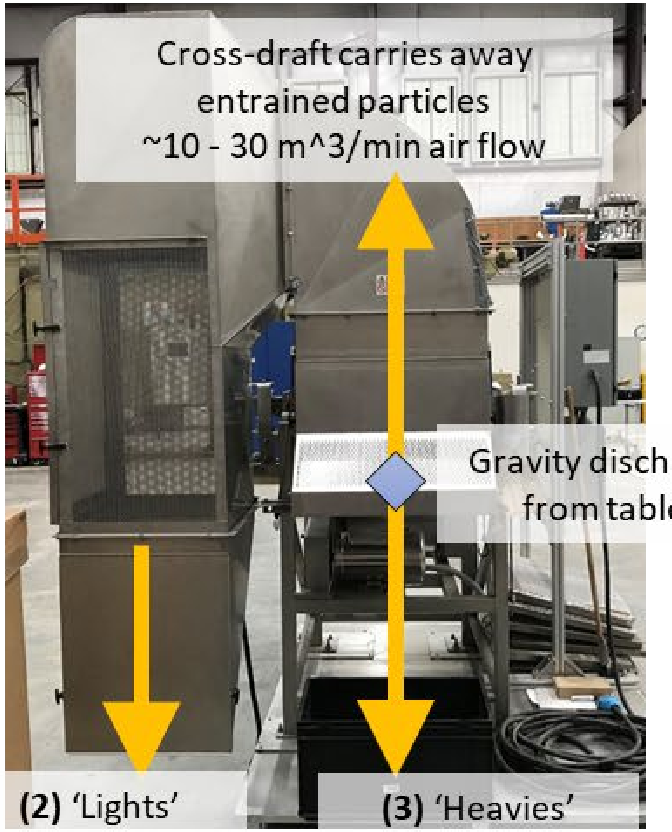
3 Potential material fractions per pass

Skid mounted unit capable of 50kg/hr

Table fit with optional sieve screen for size exclusion

(1) 'Below screen' fraction

Cross-draft carries away entrained particles ~10 - 30 m^3/min air flow



(2) 'Lights' from air-classification

(3) 'Heavies' from air-classification

2 - Approach

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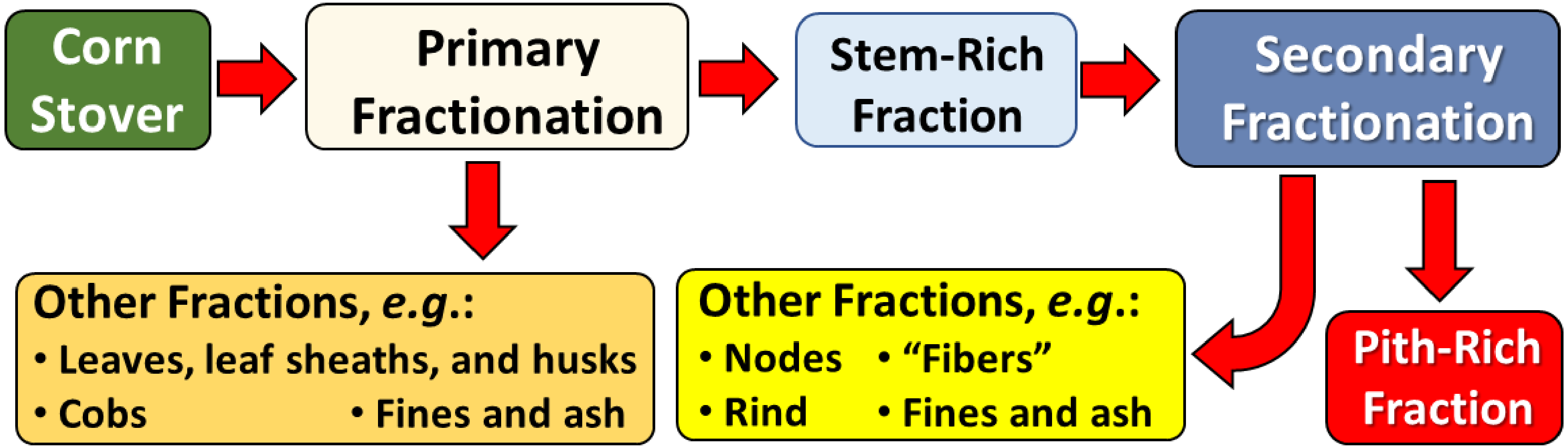


  - Primary Classification: Stem separation
    - Hammermilling, air classification
  - Secondary Classification: Pith separation
    - Shredder or hammermilling, air classification

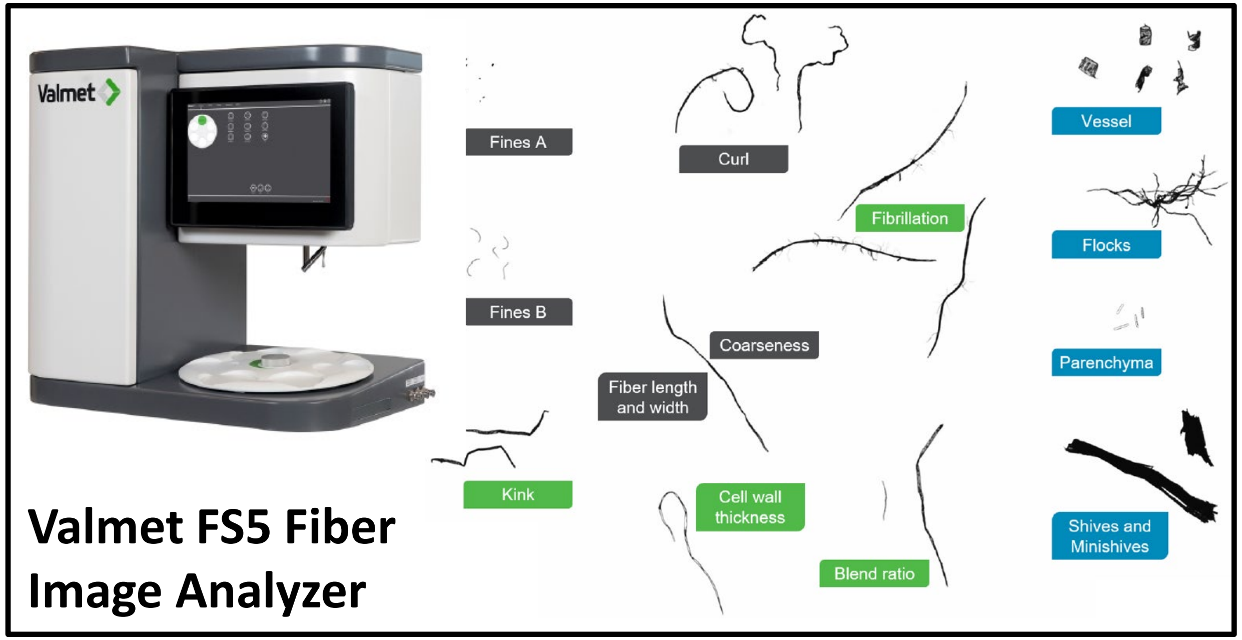
Stem Recovery at >75% yield and purity

Pith Recovery at >75% yield and purity

Go/No-Go Decision Point DP 2.2.1
In Progress (month 18)

2 - Approach

- **Tasks 3, 5**: Property characterization of physically fractionated corn stover
  - Mass composition and component partitioning
  - Particle size, aspect ratio, and tissue type



  - Characterization of sorbed water in corn stover fractions
  - Assessing response of fractionated corn stover to processing

2 - Approach

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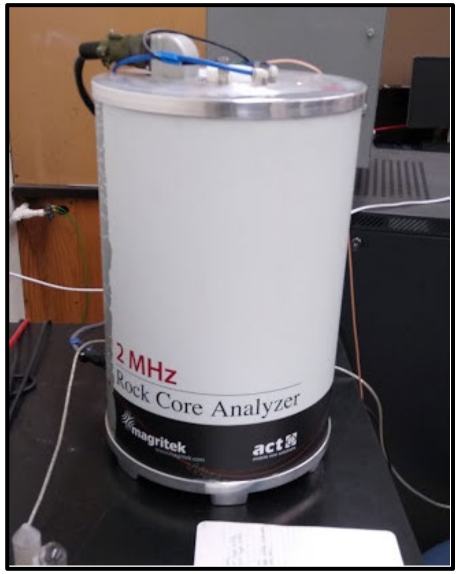

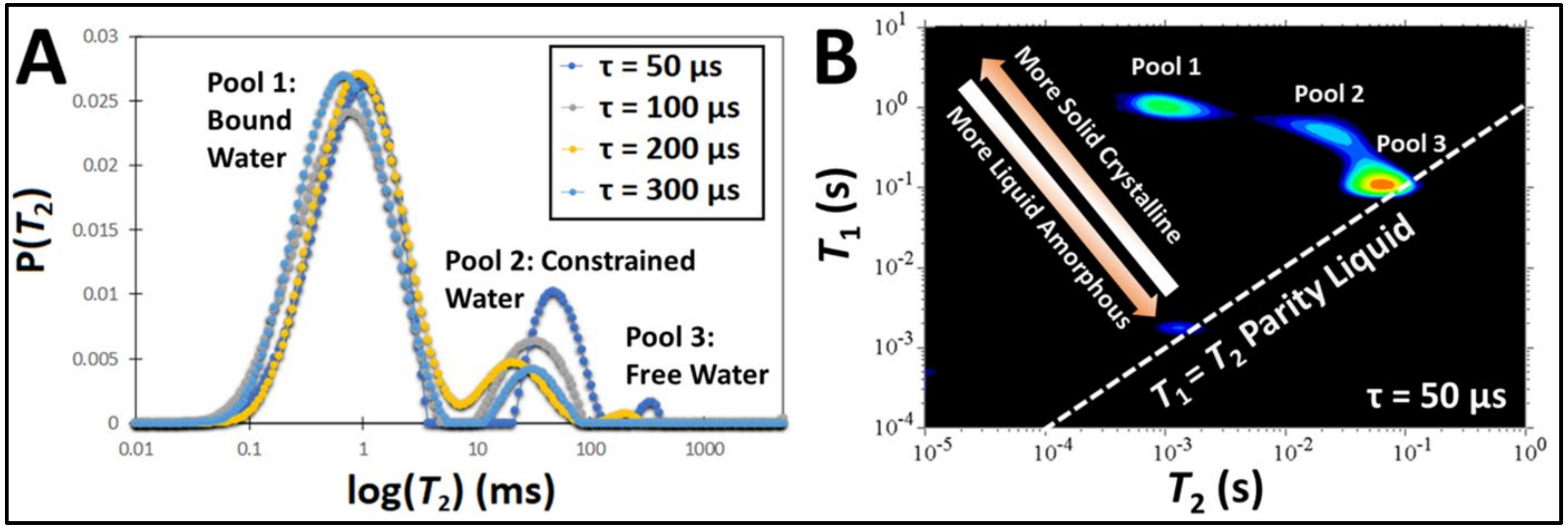

Low Field ^{1}H NMR Relaxometry

  - Assessing response of fractionated corn stover to processing

2 - Approach

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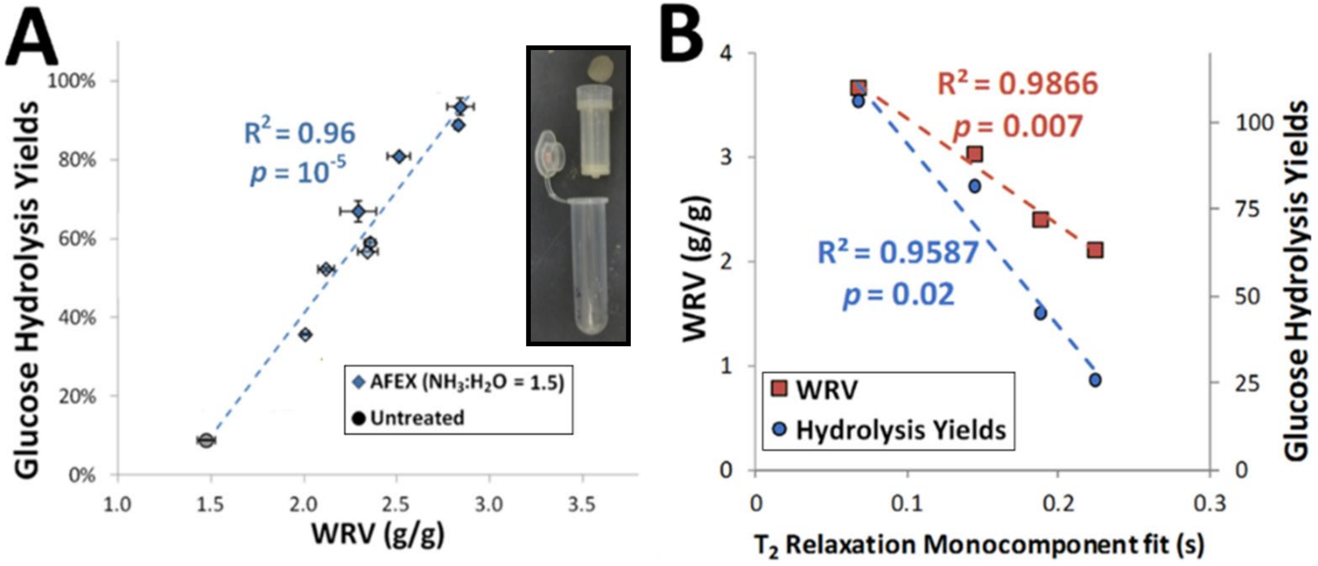

Williams and Hodge, 2014. *Cellulose.* 21, 221-235

Williams et al, 2017. *Biores Technol* 245, 242-249

Crowe et al, 2017. *J Agric Food Chem* 65, 8652-8662

Water Retention Value (WRV)

  - Assessing response of fractionated corn stover to processing

2 - Approach

- **Tasks 3, 5**: Property characterization of physically fractionated corn stover
  - Mass composition and component partitioning
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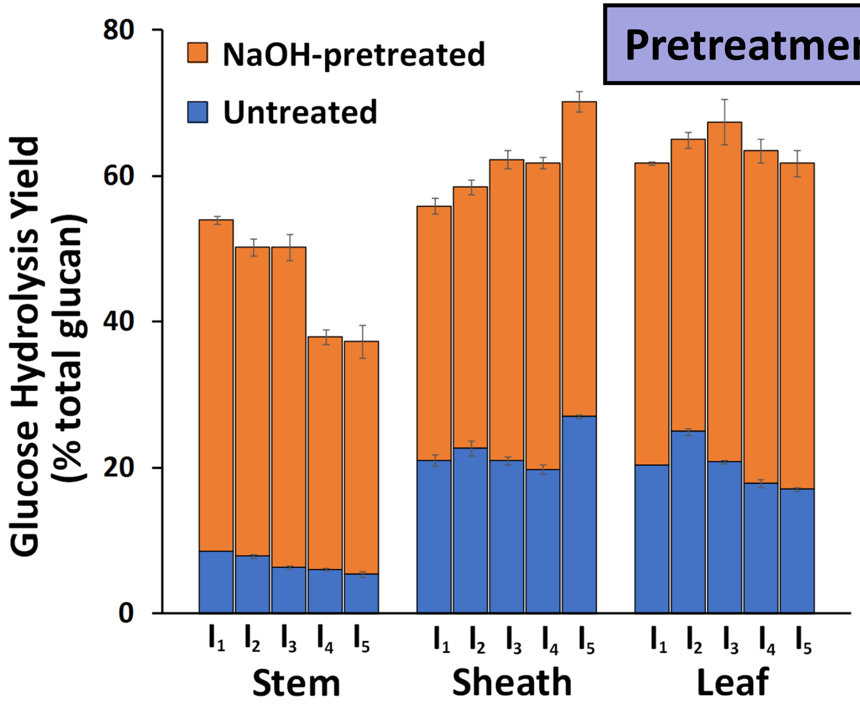
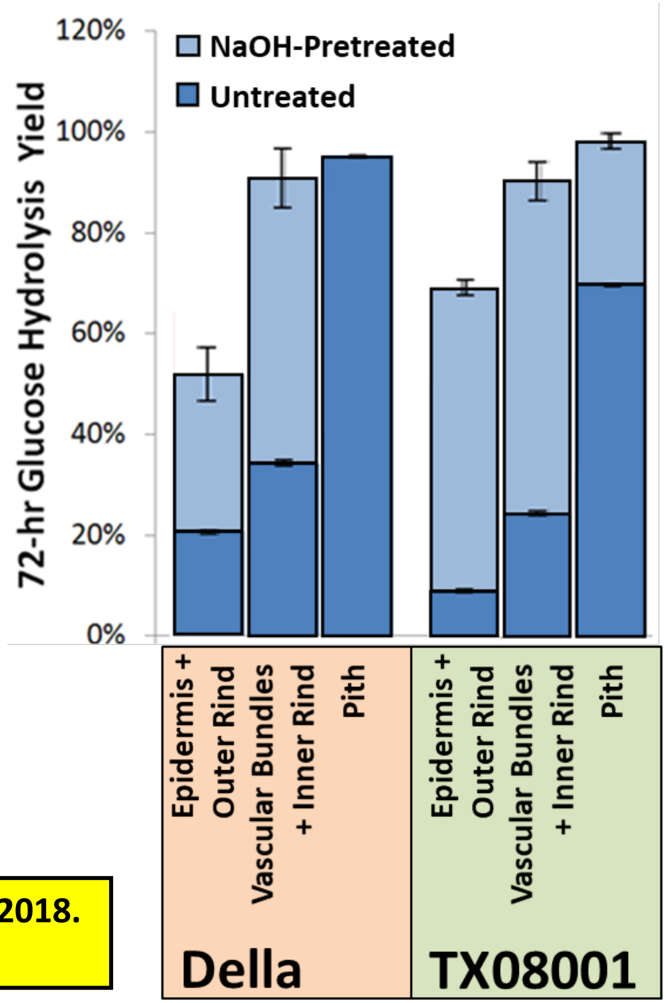


Pretreatment and Enzymatic Hydrolysis

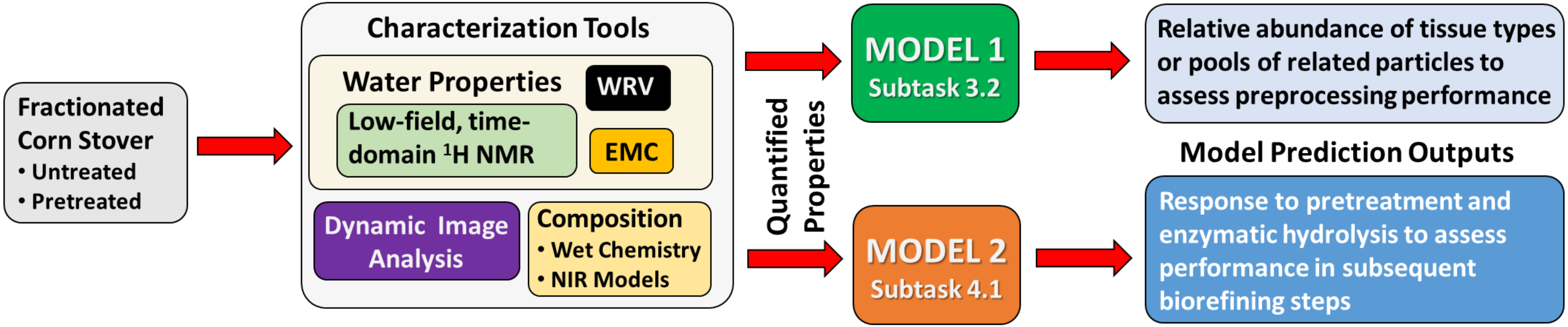
***Biotechnol Biofuels.* (2017) 10, 184**



***Ind Crop Prod.* 2018. 124, 607-616**

2 - Approach

- **Task 6**: Formulate and validate predictive models



- Empirical models to be tested:
  - Artificial neural network (ANN)
  - Partial least squares (PLS)
  - Mixed linear regression (MLR)

Li et al. *Bioenerg Res*, 2017, 10, 329

Karim and Hodge, *Biotechnol Prog*, 2003, 19, 1591

- Develop predictive models with $R^2 > 0.80$ on an independent test dataset
- End of Project Goal

- Achieve target separations
- Develop and validate robust predictive models

3 – Impact

- Develop comprehensive understanding of how corn stover properties impact preprocessing and conversion processes in a biorefinery, and inversely, how fractionation processing conditions impact the resulting biomass properties

- Develop fractionation processes for corn stover that have the potential to yield:

  (1) improved overall energy efficiency; (2) streamlined feedstock handling; (3) optimal deconstruction to cellulosic sugars at improved yields; (4) new possibilities for co-products from fractionated feedstock; (5) allowing for preprocessing in "depots" that could decouple feedstock handling from the biorefining process and address critical feedstock logistics challenges

- Develop new analytical tools to better assess and characterize the heterogeneity within corn stover and the application of these analytical tools in conjunction with empirical models to assess preprocessing performance and predict corn stover fraction responses to biorefining

3 – Impact

- Leverages prior and current DOE BETO funding and resources

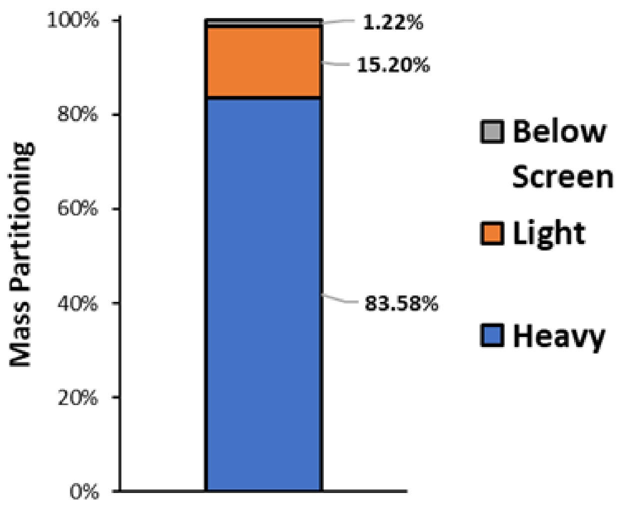
- Dissemination of results through presentations at national/international conferences, peer-reviewed journal publications

- Potential for commercialization through develop of IP and licensing technology

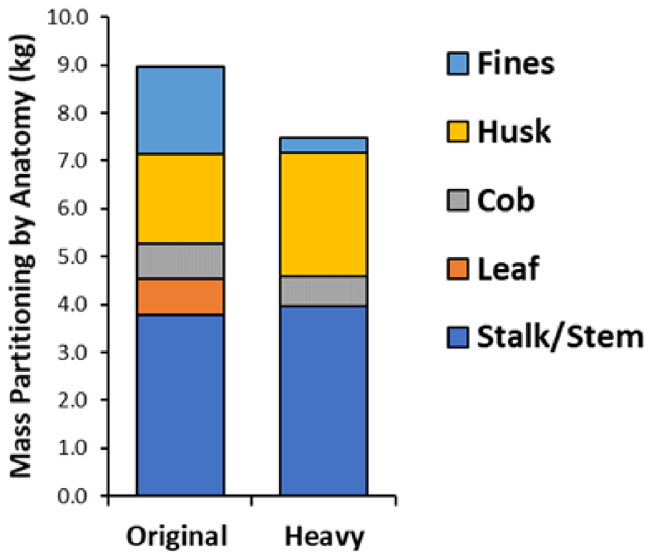
4 – Progress and Outcomes

- **Verification** completed in August 2020
  - Example first stage fractionation and characterization from **Verification**

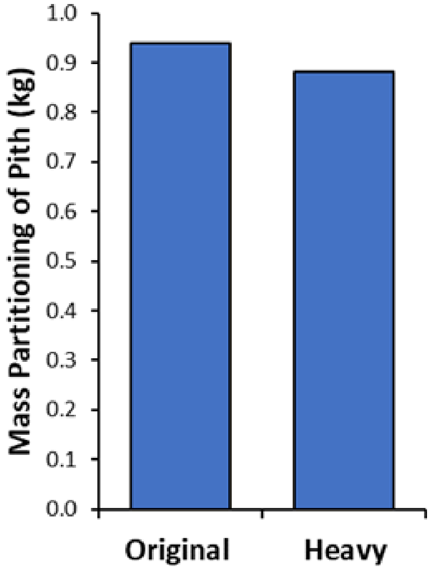
Total Mass



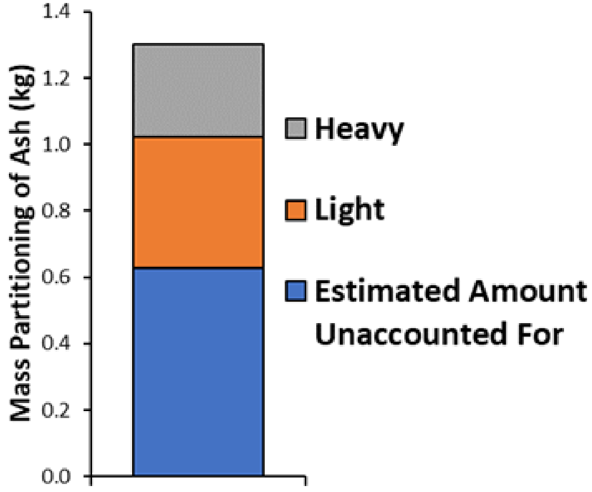
Anatomy



Pith



Ash

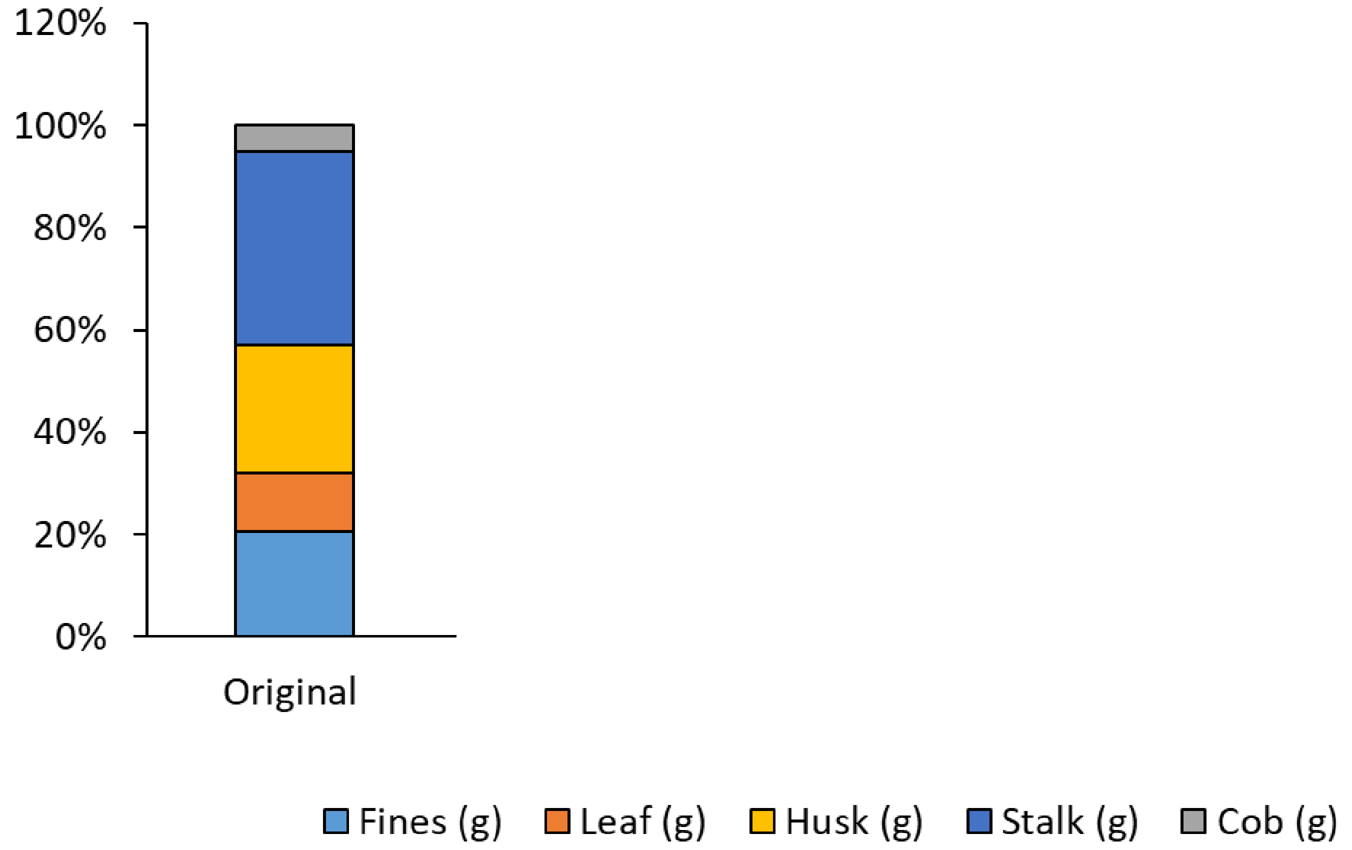


Stem Yield in 1st Stage: 105%
Stem Purity in 1st Stage: 52.9%
Pith Yield in 1st Stage: 93.9%
Pith Purity in 1st Stage: 11.8%

Ash Content in Heavy Fraction (dry basis): 3.73%
Ash Removal from Heavy Fraction (dry basis): 78.5%

4 – Progress and Outcomes

- **Verification** completed in August 2020
  - Example second stage fractionation from **Verification**



Target separations for ash removal and tissue enrichment reached

4 – Progress and Outcomes

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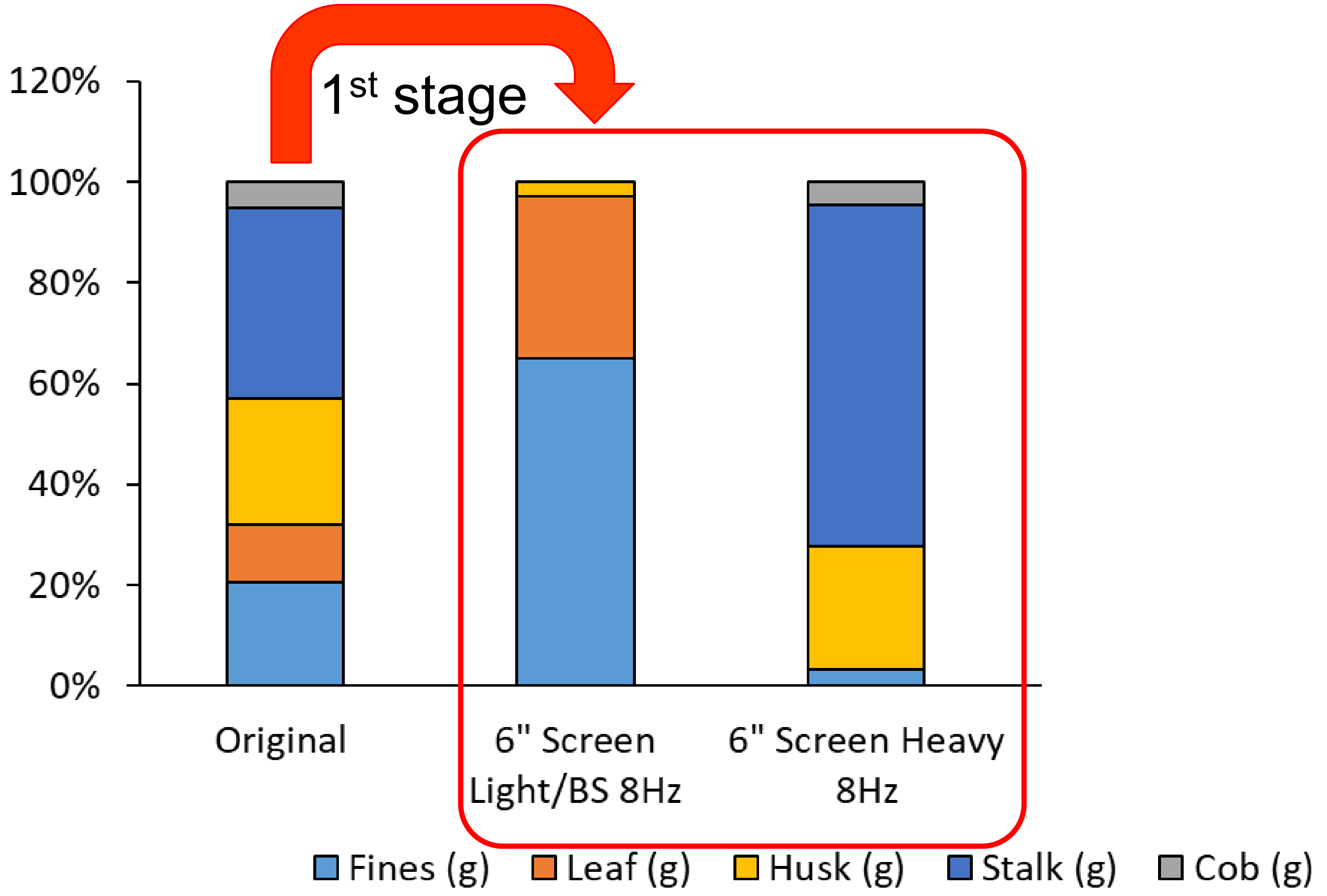

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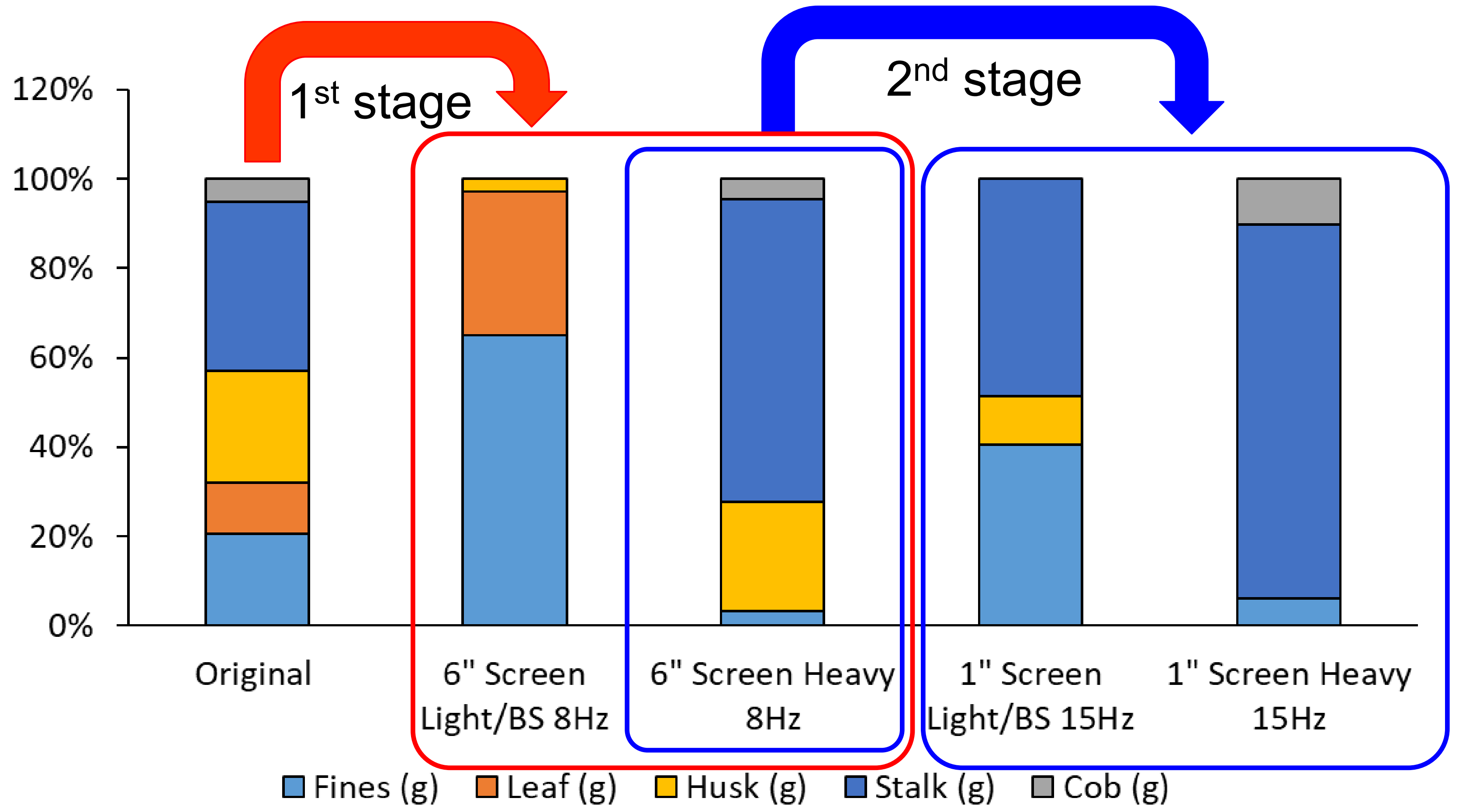
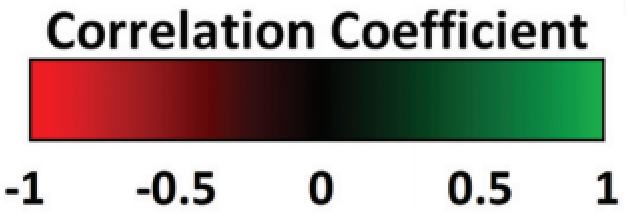


Target separations for ash removal and tissue enrichment reached

4 – Progress and Outcomes

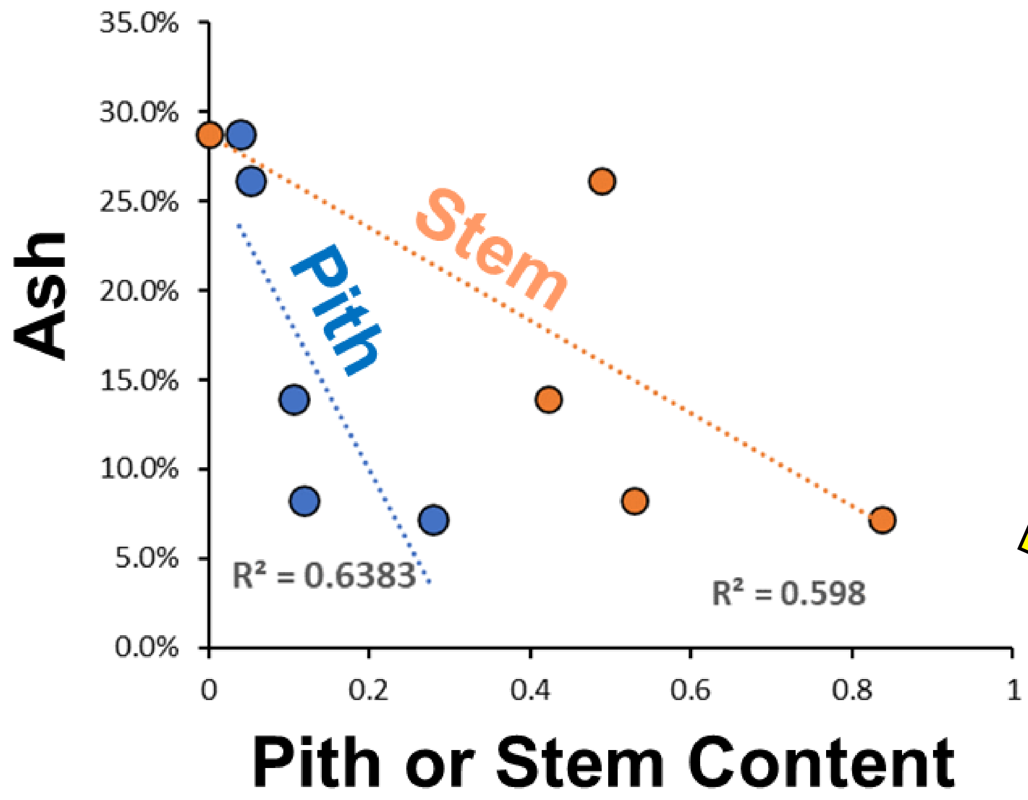
- **Verification** completed in August 2020
  - Example correlations from **Verification**

	ash - MSU new	glucan	xylan	Lignin	Lignin - post-treatment	WRV - milled	Single exp	Bi-exp b	Bi-exp d	Stem Content	Pith Content
hydrolysis - pretreated	0.493	-0.85	-0.73	-0.49	-0.6	0.002	-0.5	-0.52	-0.64	0.149	-0.09
ash - MSU new		-0.22	0.084	0.249	0.337	0.316	-0.64	-0.68	-0.51	-0.77	-0.8
glucan			0.783	0.642	0.762	0.49	0.541	0.538	0.73	-0.35	-0.35
xylan				0.391	0.71	0.107	0.441	0.417	0.638	-0.53	-0.42
Lignin					0.916	0.602	-0.28	-0.28	-0.05	-0.73	-0.55
Lignin - post-treatment						0.514	-0.1	-0.11	0.163	-0.85	-0.67
WRV							0.014	-0	0.151	-0.42	-0.74
Single exp								0.998	0.964	0.458	0.213
Bi-exp b									0.957	0.487	0.254
Bi-exp d										0.215	0.01
Stem Content											0.834



4 – Progress and Outcomes

- **Verification** completed in August 2020
  - Example correlations from **Verification**
    - Model 1: Tissue abundance



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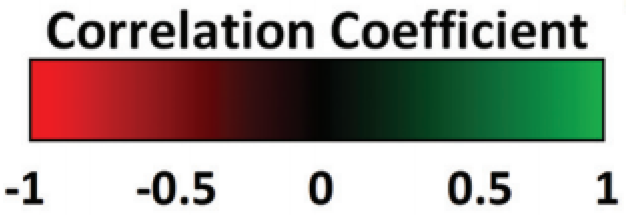

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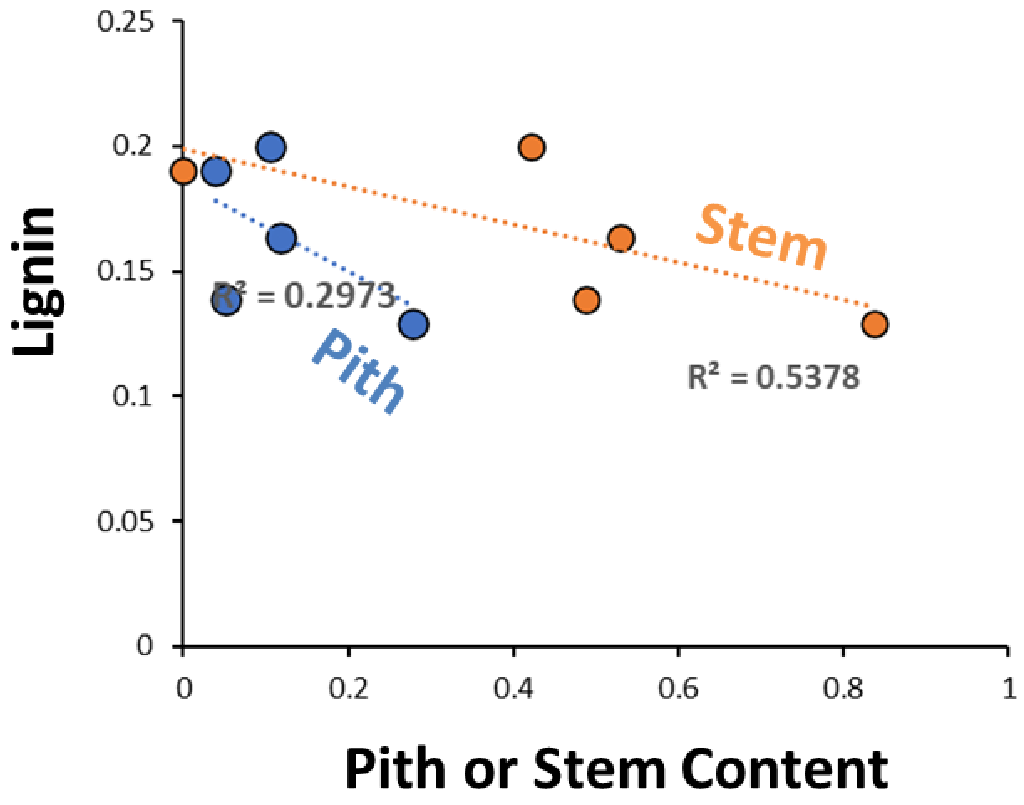

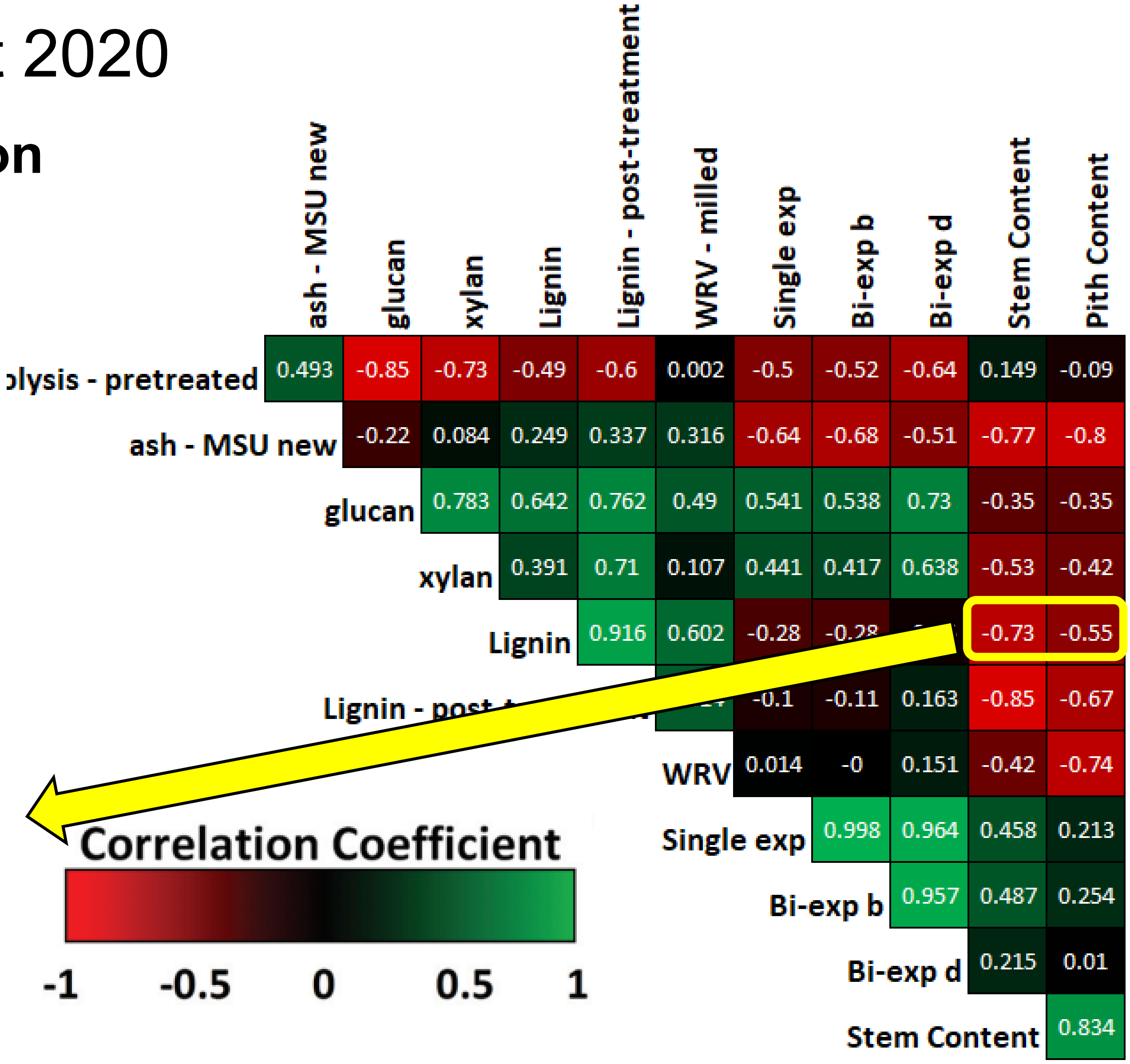

4 – Progress and Outcomes

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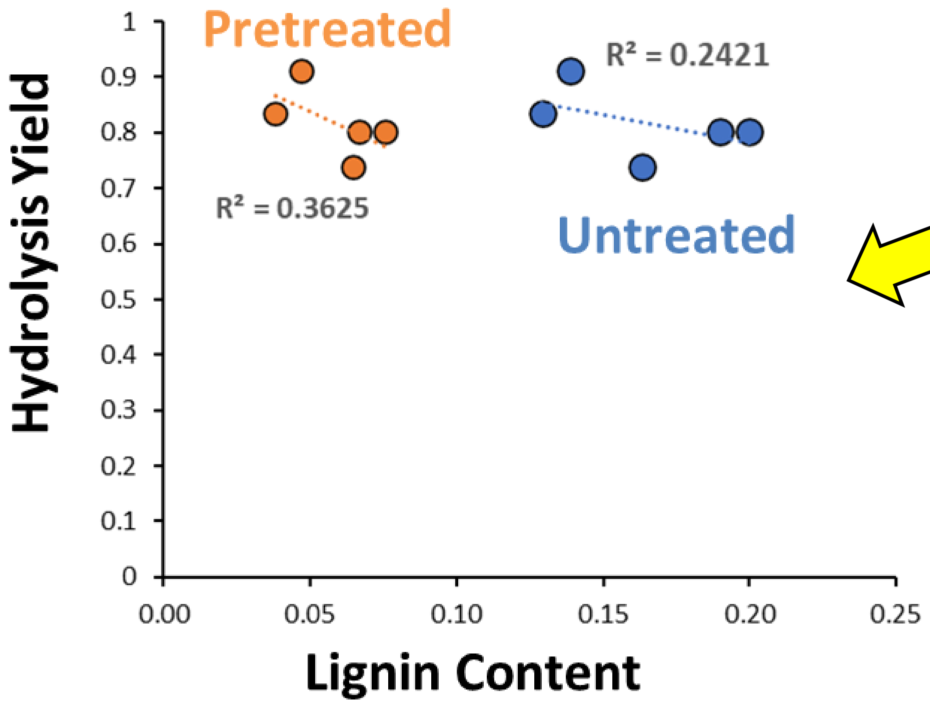
  - Example correlations from **Verification**
    - Model 2: Hydrolysis



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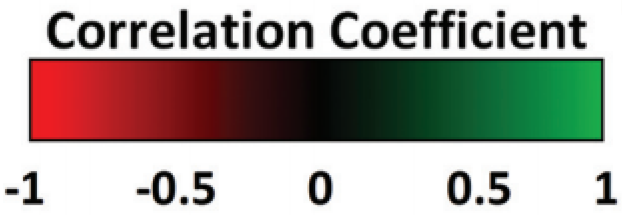

4 – Progress and Outcomes

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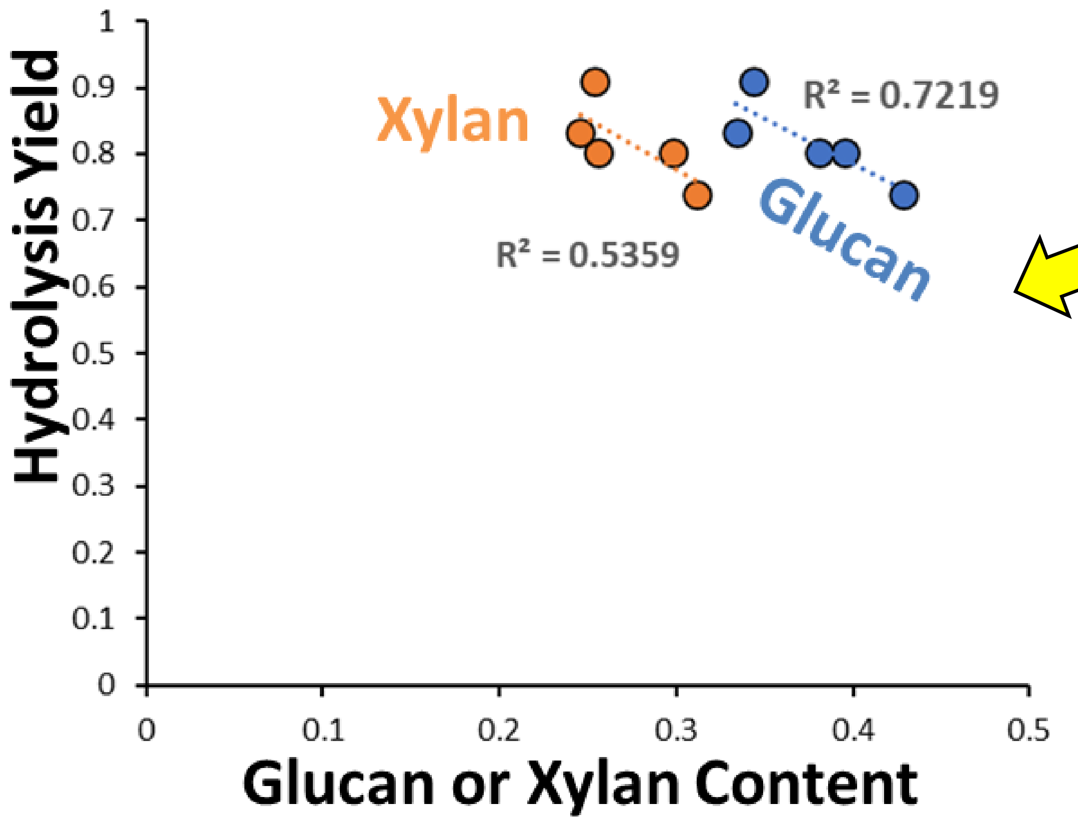
  - Example correlations from **Verification**
    - Model 2: Hydrolysis



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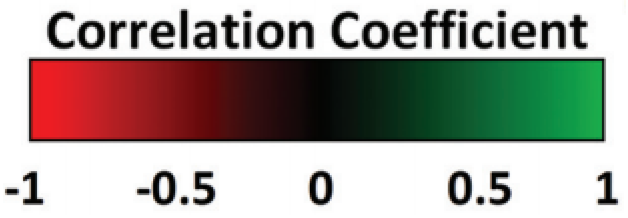
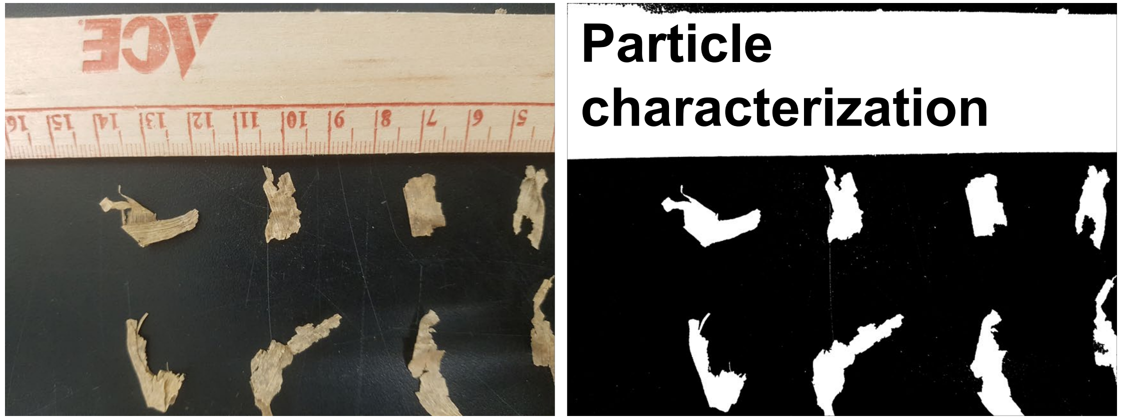


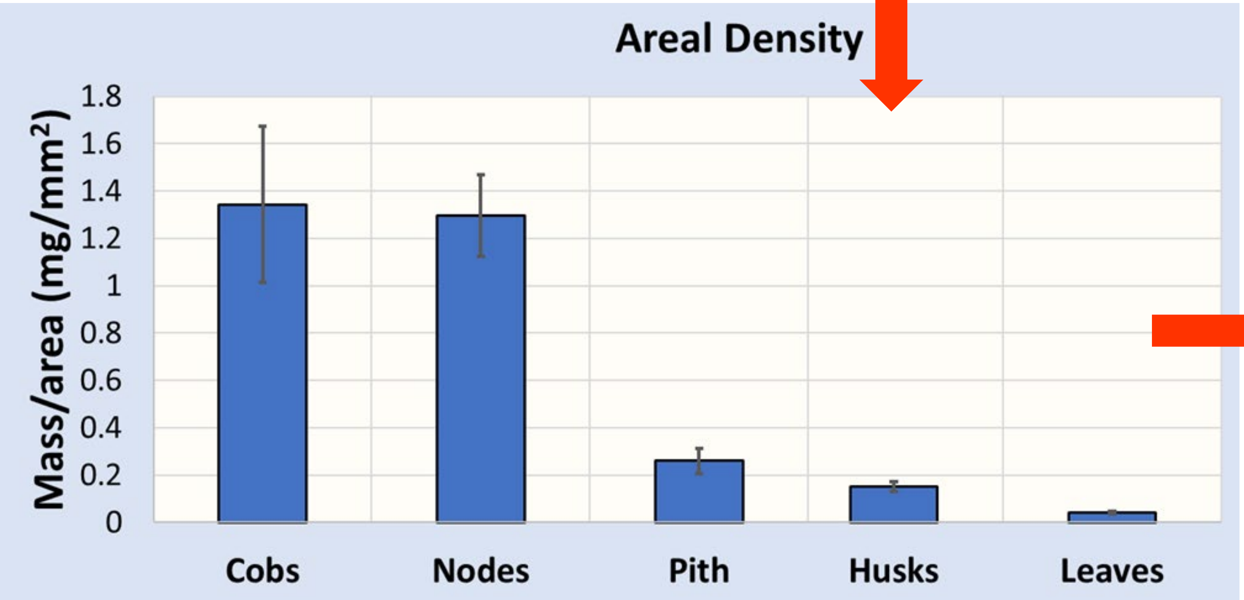
4 – Progress and Outcomes

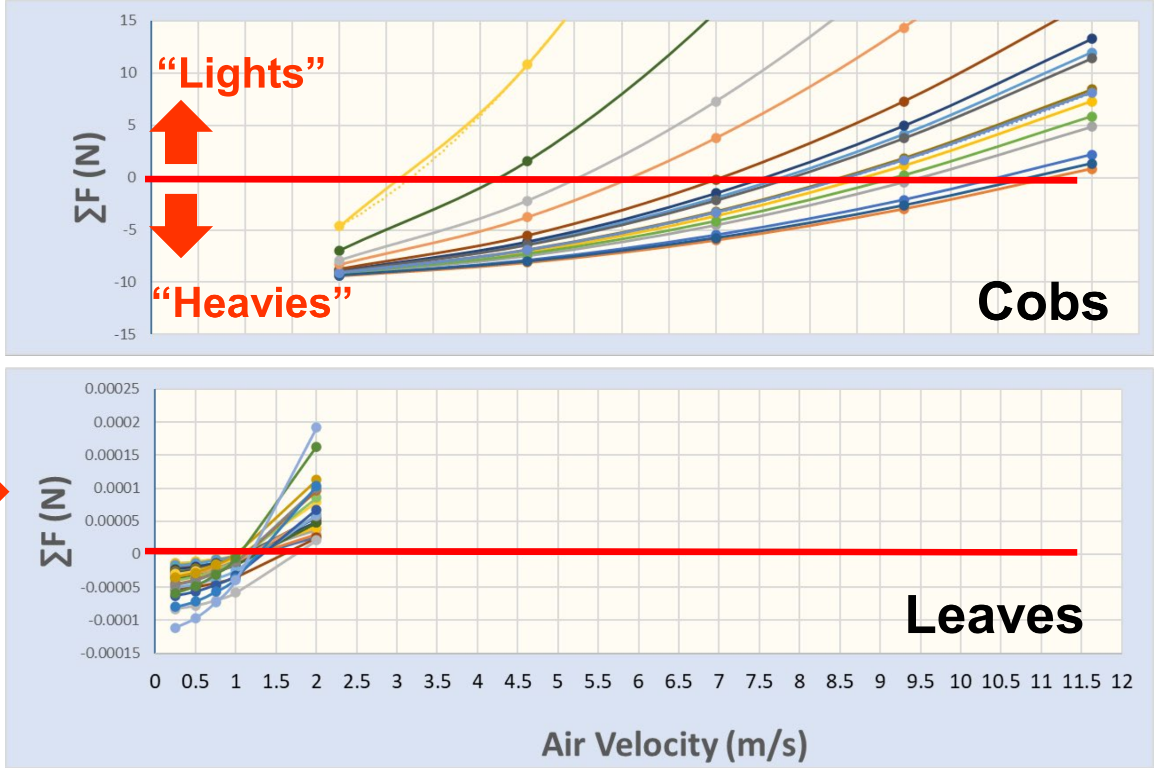
- Preliminary modeling and prediction of fractionation efficacy



$$\sum F = Mg + \frac{C_d A \rho V^2}{2} = A\left(\frac{Mg}{A} + \frac{C_d \rho V^2}{2}\right)$$

$$V = \sqrt{\frac{2Mg}{C_d A \rho}}$$ Condition for fluidization





Summary

- Verification successfully completed
- Key personnel and equipment in place
- Progress towards **Milestones** and **Go/No-Go Decisions** is ongoing

Quad Chart Overview

Timeline

- 10 January, 2020
- 30 September, 2022

	FY20 Costed	Total Award
DOE Funding	$70,147.85	$1,300,000
Project Cost Share	$23,947	$325,000

Project Partners

- Idaho National Laboratory

Project Goal

- Develop “tunable” physical fractionation technologies for corn stover
- Develop new characterization tools for assessing feedstock performance in preprocessing and conversion operations

End of Project Milestone

Achieve target separations, develop and validate robust characterization tools that either singly or in combination can serve as proxy measurements for enzymatic hydrolysis yields following pretreatment. Provide final report to DOE that includes a summary of the key findings and recommendations from the project.

Funding Mechanism

DE-EE0008907 FY19 BETO MultiTopic FOA