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U.S. Department of Energy (DOE) Bioenergy Technologies Office (BETO) 2017 Project Peer Review

2.2.1.501 Feedstock Characterization, Performance and Development

March 2017

Technology Area: Conversion Platform

This presentation does not contain any proprietary, confidential, or otherwise restricted information

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Goal and Motivation Statements

Goal

Create a systematic approach for **mapping biomass resources to conversion pathways**, forming the basis for biomass valuation, and informing when biomass preprocessing is needed to ensure feedstocks are conversion ready.

Outcome

A conversion-based biomass grading system based on key biomass characteristics with ≥85% correlation to measured conversion products from two conversion pathways, the range of variation for those characteristics across 150 commercially relevant samples, and a techno-economic methodology for categorizing the range of variation in the key characteristics.

Motivation

The first-of-a-kind cellulosic ethanol demonstration plants have struggled with **feedstock variability**, as quality variation affects performance, processing and operations. In-depth, comprehensive characterization and a grading system can be used to evaluate biomass characteristics to inform preprocessing and conversion segments on characteristics that need to be addressed.

Not every biomass material is a feedstock

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Quad Chart Overview

Timeline

- Project start date: 10/01/15
- Project end date: 09/30/18
- On-going
- Percent complete: 50%

Budget

	FY 16 Costs	Total Planned Funding, FY 17 - Project End Date
DOE Funded	$1.885M	$3.880M

Barriers addressed

- Terrestrial Feedstock Availability and Cost (Ft-A), Terrestrial Feedstock Quality, Monitoring and Impact on Conversion Performance (Ft-E), Feedstock Variability (Ct-A)
- Characterization methods and methodologies
- Convertibility testing

Collaborators

- North Carolina State University
- Sun Grant Regional Feedstock Partnership
- Consortium for Computational Physics and Chemistry (CCPC), NREL, Other INL projects
- **Seeking the collaboration of other National Laboratories**

1 - Project Overview

Diversity

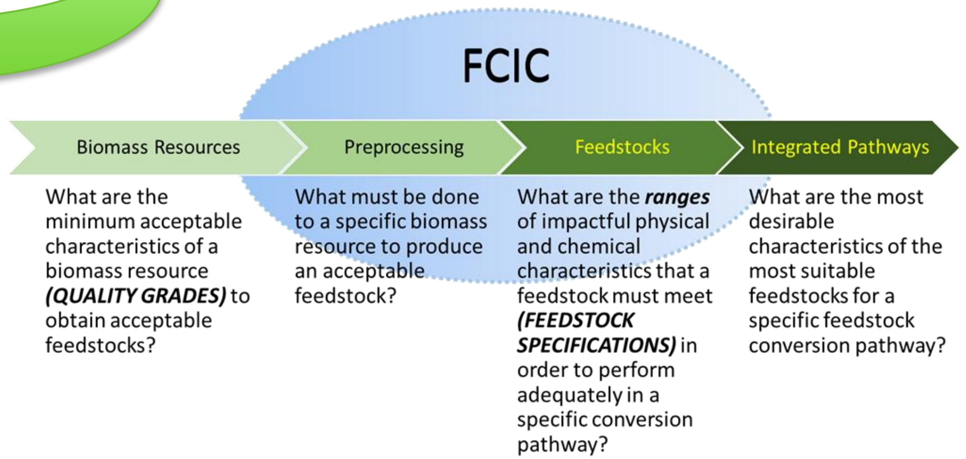
- To achieve the billion-ton vision, a diverse portfolio of biomass types and plant species will need to be included in the bioeconomy.
- Quality differences exist between species, cultivars, etc.

Variability

- Within plant species there are quality differences, because of:
  - Nutrient input
  - Seasonal variations
  - Harvest time
  - Harvest equipment, etc.

Grading System

- **Variability exhibited by biomass resources necessitates preprocessing to produce feedstocks that consistently meet process specifications**



1 - Project Overview

- Grading systems exist for commodities (e.g. crude oil), including wood for bioenergy industry end-users (heat & power)

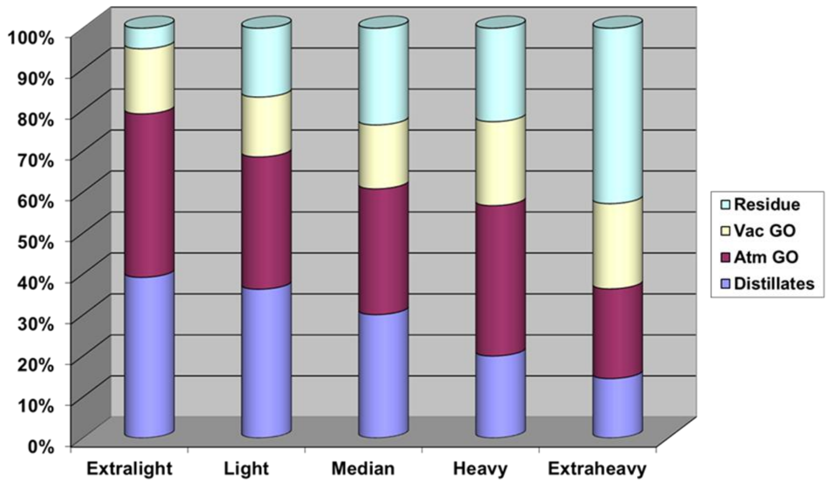
Crude Oil Industry Example:

- Key properties:
  - Density - Light to Heavy
  - S content - Sweet to Sour
  - TAN – High Acid

- Light, sweet grades require less processing and upgrading compared to heavy, sour grades

- (Quality) Grades define price, via a differential of a marker (high quality) crude, e.g.
  - Per unit of sulfur –US$0.82
  - Per unit of TAN –US$0.88
  - Per unit of API per dollar of Brent +US$0.0047

Value vs. Grades



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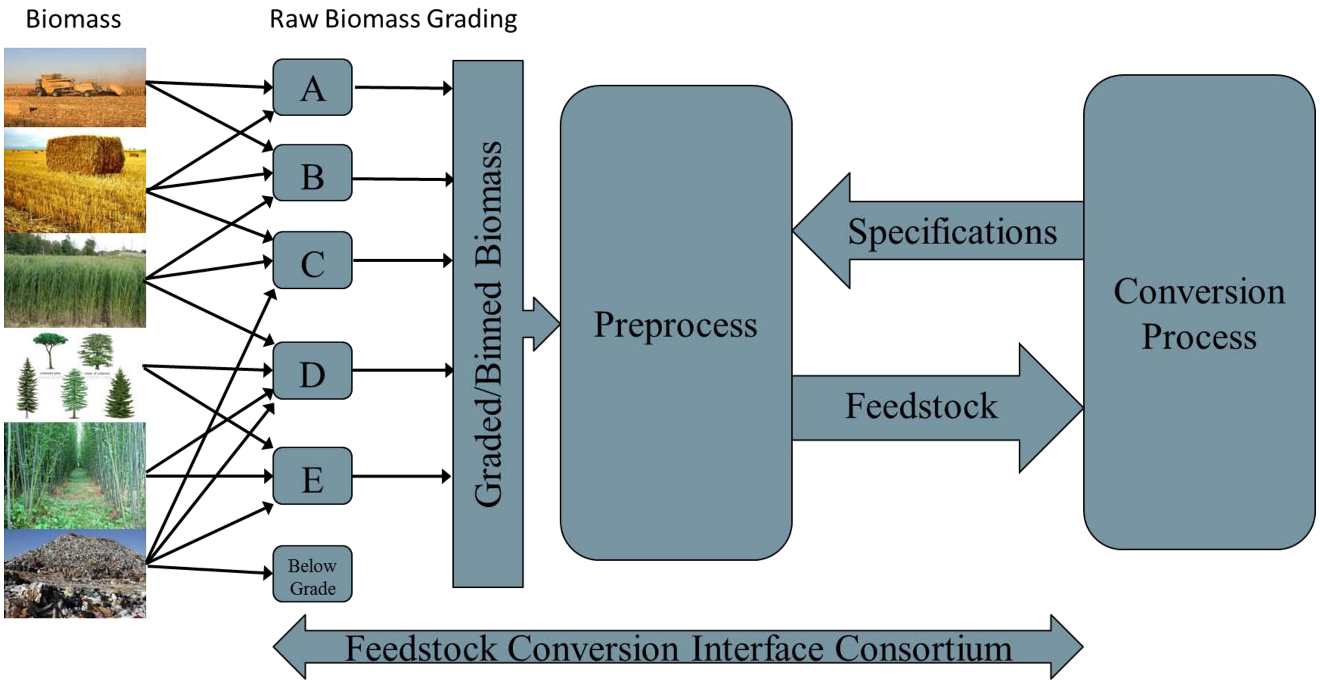
1 – Biomass Grading System for Biofuels

- **Billion Ton biomass valued on factors that do not consider full range of quality.**
- Translate biomass quality into grades meaningful to end use processes.
- **This is a large, complex, cross-cutting undertaking.**
- Underpins mobilization of the billion tons, commoditization, risk reduction/mitigation, and **rate of growth of the industry.**

Comprehensive Characterization	Define Key Characteristics	Develop Grading System	Deploy Methods/Tools
Examples: Moisture content Composition Elemental (org+inorg) Calorimetry Density Mechanical prop.	Modeling approach Examples: Sugar release Conversion	– Define grading framework – Variation range for key characteristics – Develop binning methodology – Quantify grade meanings	– Rapid, field deployable methods – Standards (e.g., ISO) – QA/QC

1 - Project Overview

- **A conversion-based biomass grading system to form the basis for valuation of biomass resources**, whereby the framework allows for future expansion of grading criteria
- The incorporation of fully characterized low-quality, low-cost biomass resources in the biofuels supply chain **to meet cost, quality and volume goals**



2 – Approach

Technical

1. Identification of **key characteristics affecting conversion**. The goal is to determine the minimum number of characteristics relevant to conversion that need to be included in a grading system.
2. Data (histograms) of **representative distributions of the characteristics** identified in #1 and determination of the variability ranges for the diversity of biomass resources.
3. A **binning methodology** that provides economic or technical rationale for categorizing data from #2 into grades. These ranges of variability then need to be graded (i.e., binned) in a meaningful way.

Challenges

- **Uniqueness**: No grading system exists today for a biofuels industry end-user.
- **Uncertainty**: Technology for all parts of the supply chain and biorefineries are in development.
- **Data**: No comprehensive characterization data exists for a range of biomass materials.
- **Knowledge**: Critical relationships between biomass properties and performance are unknown.

2 – Approach (Management)

- **Network with projects on the** supply side **(upstream) and on** the preprocessing side **(downstream)**.
- Identification of the key characteristics relies on the **accurate assessment of the properties** to address intrinsic material variability.
- **Work with partners and collaborators.**

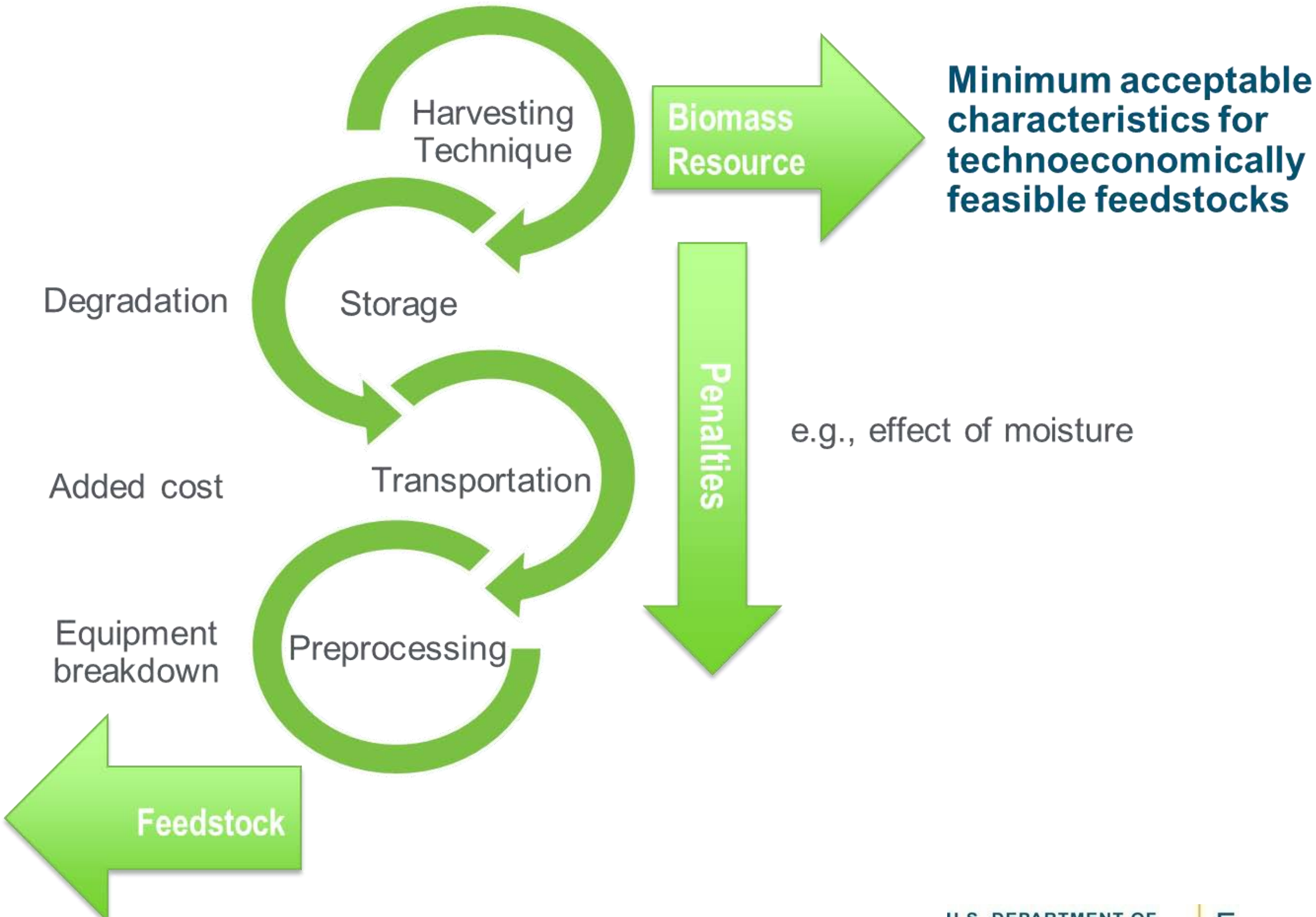
Success Factors:

- Establish the technical rationale for selection of key characteristics that could be measured using rapid, online, field deployable methods.
- Establish the technical rationale for bin ranges of key characteristics and consistency within grades and downstream processes.
- Establish a **preliminary grading system** with no more than six grades per end use.
- Quantify penalties.

Go/No-Go Milestone: Demonstrate that a preliminary conversion-based biomass grading system could be established for one representative biochemical and one representative thermochemical conversion pathway (Due in March 2017).

3 – Technical Accomplishments: Grading Framework

- No framework was previously established for grading biomass for the biofuels industry.
- The **framework developed** in this project is the technical and economic foundation that supports the grades and provides a transparent rationale for the system.



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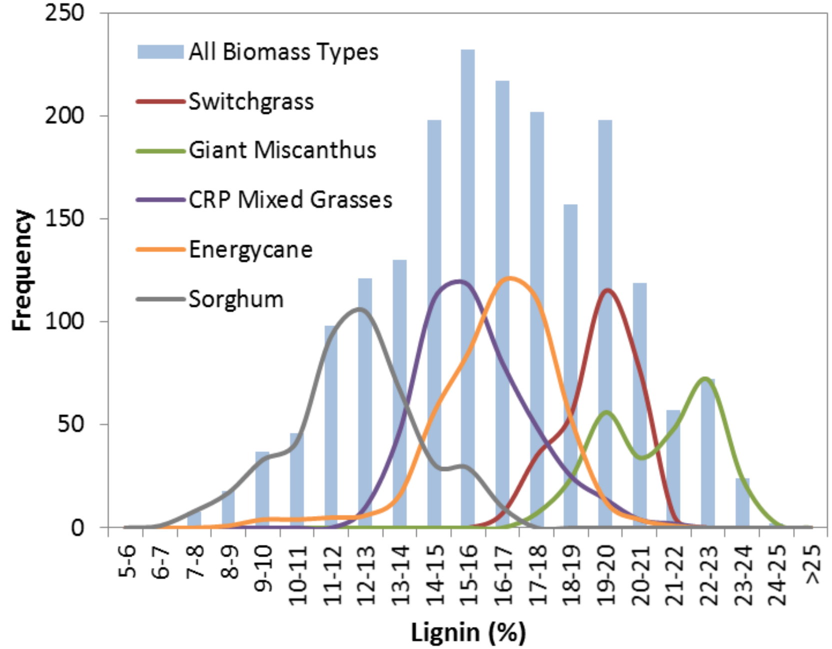
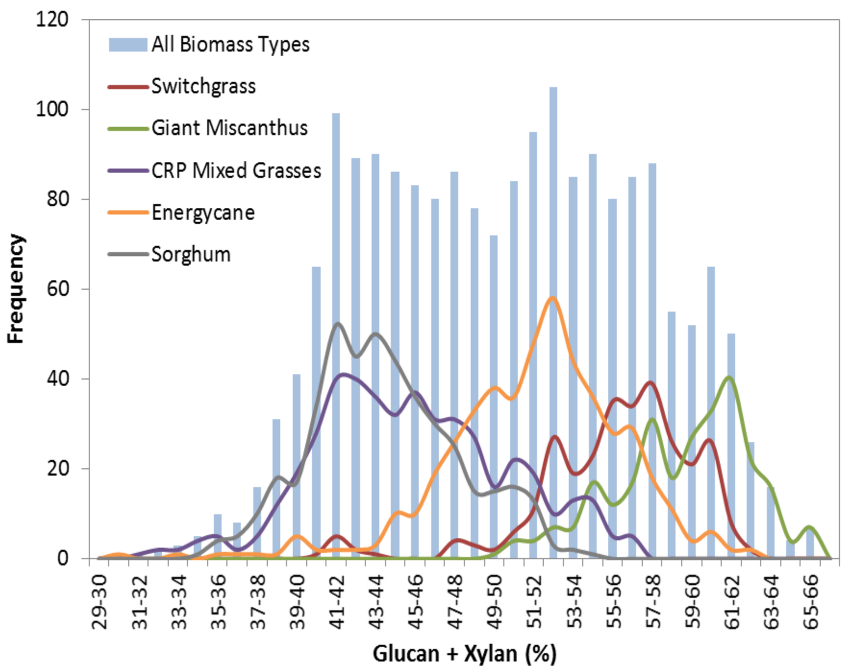
3 – Technical Accomplishments: Characteristic Distributions

- **Identified the extent of biomass quality variation** by partnering with the Sun Grant Regional Feedstock Partnership.
- Composition & proximate/ultimate for ~2,000 samples from diverse crop types.
- Variability from crop years, geographic locations, & research treatments.





- A grading system must incorporate a few characteristics measurable at field/roadside.
- Characteristics must impact performance.
- Characteristics must vary, otherwise they don't need to be graded.

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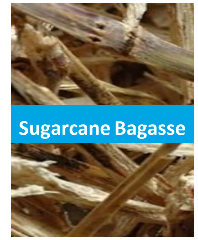
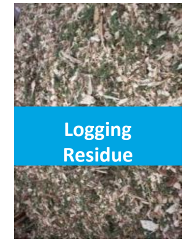
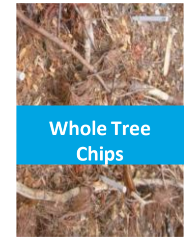
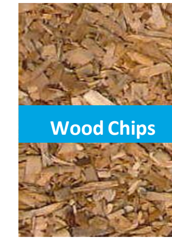
3 – Technical Accomplishments: Characterization

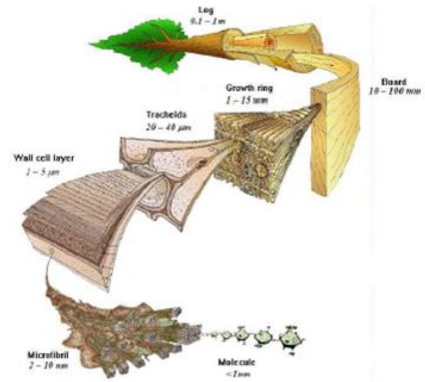
- **Grades will expand beyond composition and conversion as knowledge is gained.**
- Mechanical Properties
  - Grindability
  - Flowability
  - Fluidization
  - Agglomeration
- Physical Properties
  - Density: Mass vs Energy
  - Structure
- Chemical Properties
  - Composition
  - Reactivity
- Physicochemical
  - Solubility
  - Wettability



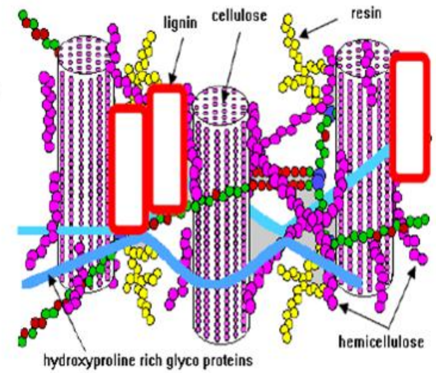




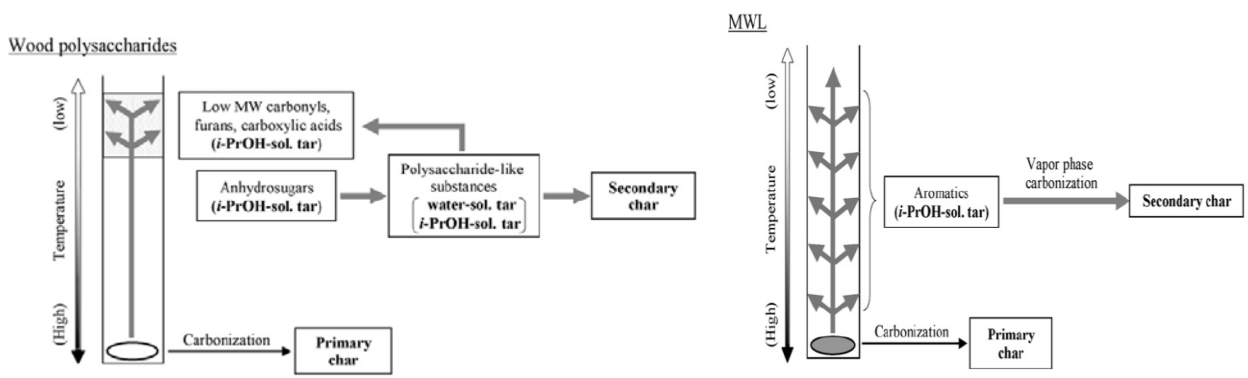




Wood Physical Structure



Wood Microscopic Structure



Source: T. Hosoya et al. ***J. Anal. Appl. Pyr.*** 78 (2007) 328

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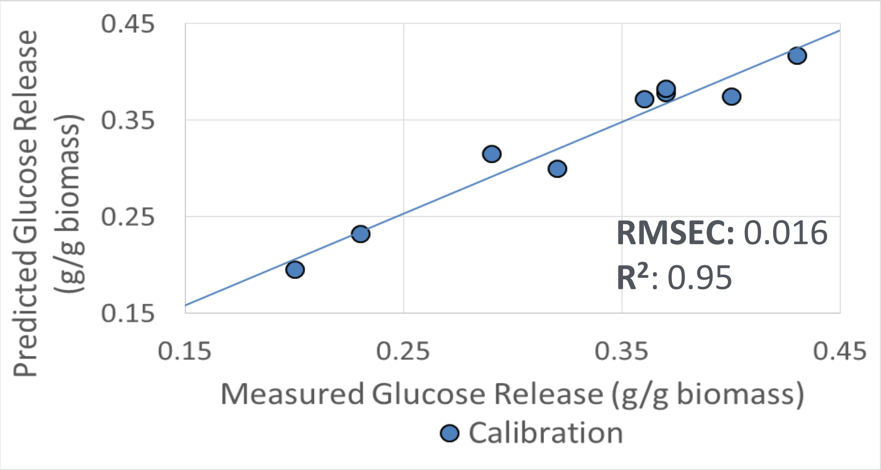
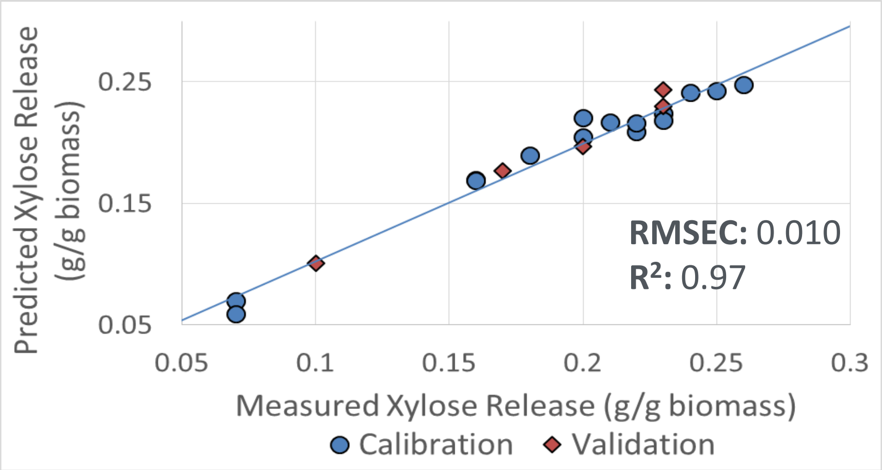
3 – Technical Accomplishments: BC Key Characteristics

- **Used a modeling approach and literature review to identify 3 key characteristics**
- Literature: Negative relationship between **lignin** and sugar release in literature
- Experimental Results:
  - Response: dilute-acid pretreatment and enzymatic hydrolysis sugar release
  - Predictor variables: chemical composition
  - Key characteristics: **glucan & xylan** necessary to account for sugar release
- Experiments ongoing using additional pretreatment severities and enzyme loadings



Glucan used to predict sugar release



Xylan used to predict sugar release

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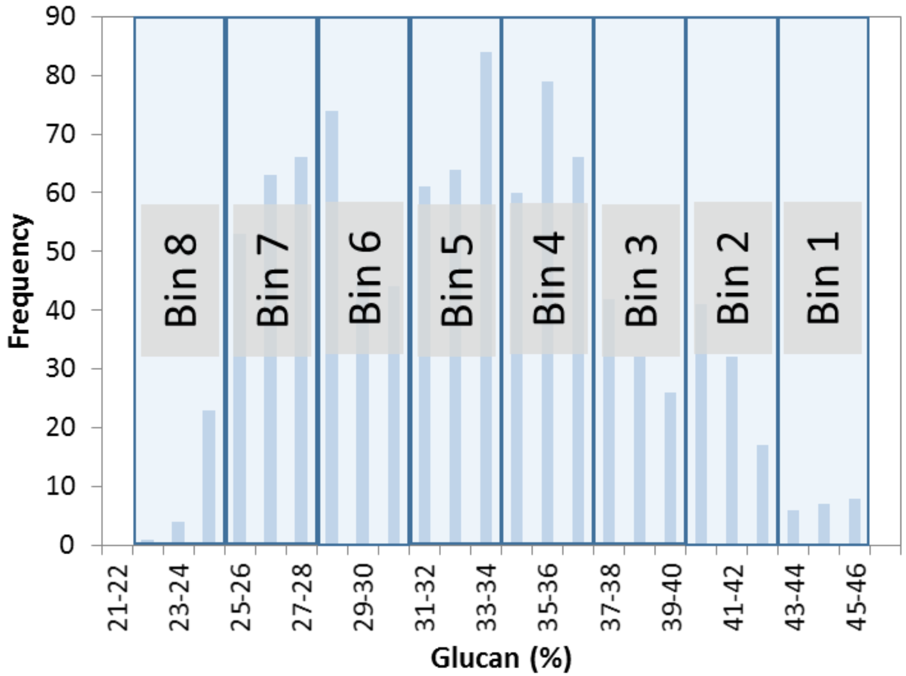
3 – Technical Accomplishments: Binning Methodology

- **Binned glucan, xylan and lignin considering analytical uncertainty and variability**
- Represents the maximum number of possible bins



	%Glucan	%Xylan	%Lignin
Bin 1	46-43	26-24	6-9
Bin 2	43-40	24-22	9-12
Bin 3	40-37	22-20	12-15
Bin 4	37-34	20-18	15-18
Bin 5	34-31	18-16	18-21
Bin 6	31-28	16-14	21-24
Bin 7	28-25	14-12	24-27
Bin 8	25-22	12-10	

- Variability ranges have to be feasible and industrially relevant
- Future work aimed at generating bins based on additional technical rationale (e.g., cost)

3 – Technical Accomplishments: Binning Methodology

- Example: Commercially Relevant Miscanthus

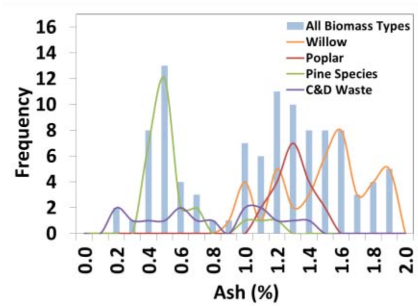
	%Glucan	%Xylan	%Lignin
Wet Chemical Composition	40.79	22.01	20.41

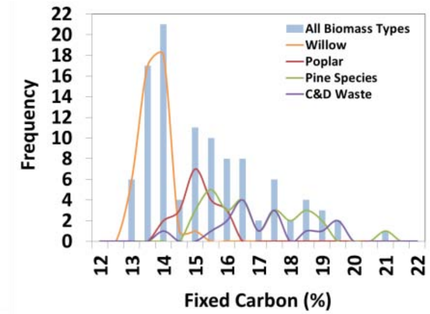
	%Glucan	%Xylan	%Lignin
Bin 1	46-43	26-24	6-9
Bin 2	43-40	24-22	9-12
Bin 3	40-37	22-20	12-15
Bin 4	37-34	20-18	15-18
Bin 5	34-31	18-16	18-21
Bin 6	31-28	16-14	21-24
Bin 7	28-25	14-12	24-27
Bin 8	25-22	12-10	

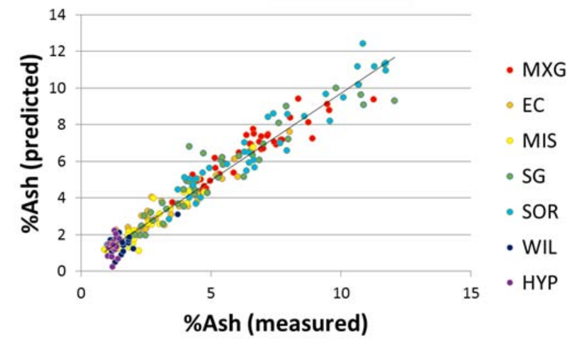
- Future work aimed at generating **the minimum number of bins necessary for each component**
- This will allow for a system more like crude oil (e.g., light, sweet compared to heavy, sour grades)

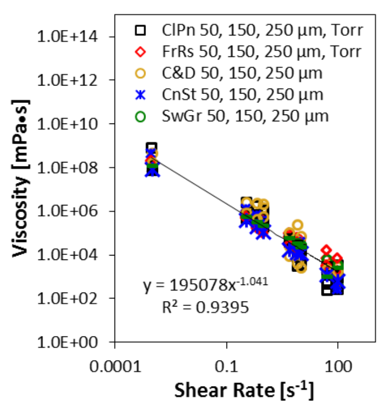
3 – Technical Accomplishments: TC Pathway

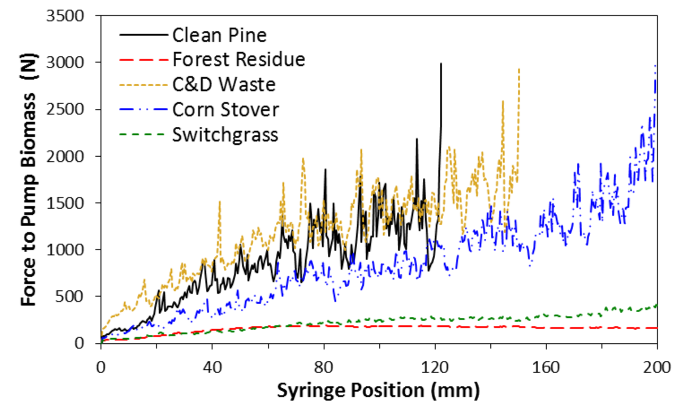
- **Same technical approach for TC as BC pathway.**
- **105 samples characterized**
- **Advanced multivariate model techniques:**
  - FT-NIR spectroscopy for proximate/ultimate properties
  - Reductions in prediction error
- **HTL Rheology:**
  - Parallel plate viscosities showed no differences with biomass type, size, or pretreatment.
  - Developed a pumpability metric for determination of biomass slurry dewatering and plugging potential.
- **Collaboration w/ CCPC & Univ. of Minnesota:**
  - Deeper understanding of conversion effects











4 – Relevance

Impact

Grades will set the price scale on the supply side, enabling creation of a market. On the demand side, grades would set the baseline for determining the necessity of preprocessing to produce conversion-ready biomass feedstocks.

Use

- A grading system can be used to evaluate biomass characteristics and preprocessing options enabling incorporation of low-quality, low-cost materials in the biofuels production process to meet cost, quality and volume goals.
- The **in-depth, comprehensive characterization of biomass resources can inform the preprocessing and conversion segments** on characteristics that need addressed.
- The framework established will be the basis for future expansion of grading criteria.

Industrial Stakeholders

The comprehensive characterization data of the different **grades will set the basis for the definition of feedstock specifications** for the various conversion processes in close coordination with other FCIC projects that will include the preprocessing and conversion projects.

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5 – Future Work

- Develop a proxy for the TC conversion of biomass
- TC collaborations: (1) PSD & Shape, (2) thermal transport properties and (3) kinetics
- Select key properties that also could be measured using rapid, online, field deployable methods
- Bin ranges of key properties & establish consistency within grades and downstream processes
- Define roll out and implementation plan, including:
  - R&D for development of rapid, online, field deployable methods
  - Standardization
  - Quality Management & Quality Assurance

Summary

- **Overview: A Grading System is needed since the variability of biomass resources necessitates preprocessing to produce consistent feedstocks that meet process specifications.**
- Approach: A simple three-step procedure, including a binning methodology and an extensive network of collaborators and partners to facilitate the solution of a complex problem.
- Accomplishments: A framework that provides the principles for the economic and technical rationale of quality grades.
- **Relevance and Impact: Grading not only sets the price scale for the supply side and the preprocessing needs for the demand side, but also will allow incorporation of low-cost and/or low-quality resources.**

Additional Slides

Responses to Previous Reviewers' Comments

- If your project is an ongoing project that was reviewed previously, address 1-3 significant questions/criticisms from the previous reviewers' comments (refer to the 2013 Peer Review Report, see notes section below)
  - **This project began in FY16 and was not peer reviewed in FY15.**
- Also provide highlights from any Go/No-Go Reviews
  - **The Go/No-Go for this project has not occurred, and will be completed in March 2017.**

Note: This slide is for the use of the Peer Reviewers only – it is not to be presented as part of your oral presentation. These Additional Slides will be included in the copy of your presentation that will be made available to the Reviewers.

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Publications

- Aston, J., Thompson, D., Westover, T. 2016. Performance Assessment of Dilute-Acid Leaching to Improve Corn Stover Quality for Thermochemical Conversion. Fuels, 186, 331-319.
- Groenewold, G., Johnson, K. Fox, S., Rae, C. Zarzana, C., Kersten, B., Rowe, S., Westover, T., Gresham, G., Emerson, R., Hoover, A. 2017. Pyrolysis Two-Dimensional GC-MS of Miscanthus Biomass: Quantitative Measurement using an Internal Standard Method. *Energy & Fuels*. DOI: 10.1021/acs.energyfuels.6b02645.
- Hu, H., Westover, T., Aston, J., Lacey, J. 2016. Process Simulation and Cost Analysis for Removing Inorganics from Wood Chips using Combined Mechanical and Chemical Preprocessing. BioEnergy Research. DOI:10.1007/s12155-016-9794-3.
- Lacey, J., Emerson, R., Westover, T., Thompson, D. 2016. Ash Reduction Strategies in Corn Stover Facilitated by Anatomical and Size Fractionation. Biomass and Bioenergy, 90, 173-180.
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Publications

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- Wahlen, B., Wendt, L., Mohammad, R., Newby, D., Westover, T., Stevens, D., Cafferty K., Logistics Analysis of a Feedstock Blending Strategy to Manage Variability in Algal Productivity. Submitted to Algal Research.
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- Williams, C., Westover, T., Petkovic, L., Matthews, A., Stevens, D., Nelson, K. 2017. Determining Thermal Transport Properties for Softwoods Under Pyrolysis Conditions. ACS Sustainable Chemistry & Engineering, 5(1), 1019-1025. DOI: 10.1021/acssuschemeng.6b02326.

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- Emerson, R., Westover, T., Hoover, A., Gresham, G. Rapid Screening Processes for Determining Important Quality Attributes in Biomass Using Spectroscopic Techniques. Poster Presentation, Tcbiomass2015. Nov. 2015.
- Emerson, R. "Regional Feedstock Partnership: DOE Bioenergy Feedstock Library". Regional Feedstock Partnership Close-out Meeting. Washington, DC. July 14, 2016.
- Emerson, R.; Walker, V.; Hoover, A.; Cortez, M.; Kinoshita, R.; Gresham, G., "Quantifying Biomass Feedstock Variability Using the DOE Bioenergy Feedstock Library". 38th Symposium on Biotechnology for Fuels and Chemicals, Feedstocks (III) Track. Baltimore, MD. April 27, 2016.
- Emerson, R.; Kalivas, J., "Rethinking Local Calibration using Local Adaptive Fusion Regression". SciX 2016, Rethinking Calibration. Minneapolis, MN. September 21, 2016.
- Fox, S., Emerson, R., Hoover, A., Walker, V., Gresham, G. Using the DOE Bioenergy Feedstock Library as a tool for lignin structure/property relationship research. Oral Presentation, American Chemistry Society National Meeting. San Diego, CA. March 13, 2016.
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Presentations

- Hoover, A., Stevens, D., Ray, A., Vega, L., Emerson, R., Hoeger, I., Park, S., Gresham, G. Predicting bioconversion from physical and chemical characteristics of multiple lignocellulosic biomass types. Poster Presentation/Rapid Fire Poster Showcase Presentation, 38th Symposium on Biotechnology for Fuels and Chemicals. Baltimore, MD. April 26th, 2016.
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- Westover, T. Selected emerging market opportunities for torrefied biomass. Invited Presentation in webinar: Torrefied Biomass: New Markets, New Directions, New World. Presented by The World Bioenergy Association and the International Biomass Torrefaction Council. June 22, 2016.
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