

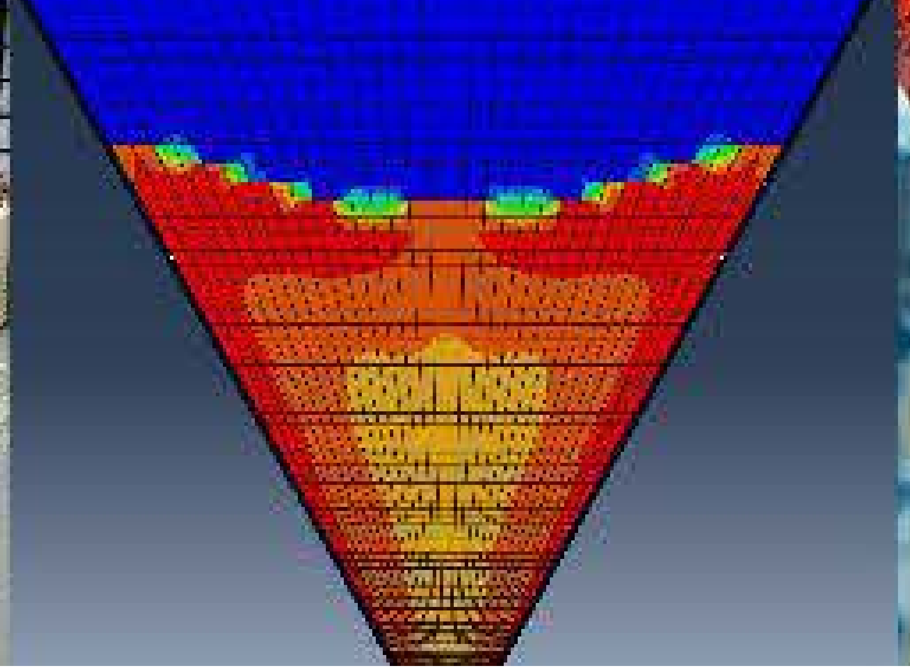


The Feedstock-Conversion Interface Consortium – Understanding and Mitigating the Impacts of Feedstock Variability in Bioconversion Processes

Edward J. Wolfrum, FCIC Principal Investigator

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ABLCNEXT2022

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

1-slide guide to the FCIC

The Feedstock-Conversion Interface Consortium is led by DOE as a collaborative effort among researchers from 9 National Labs

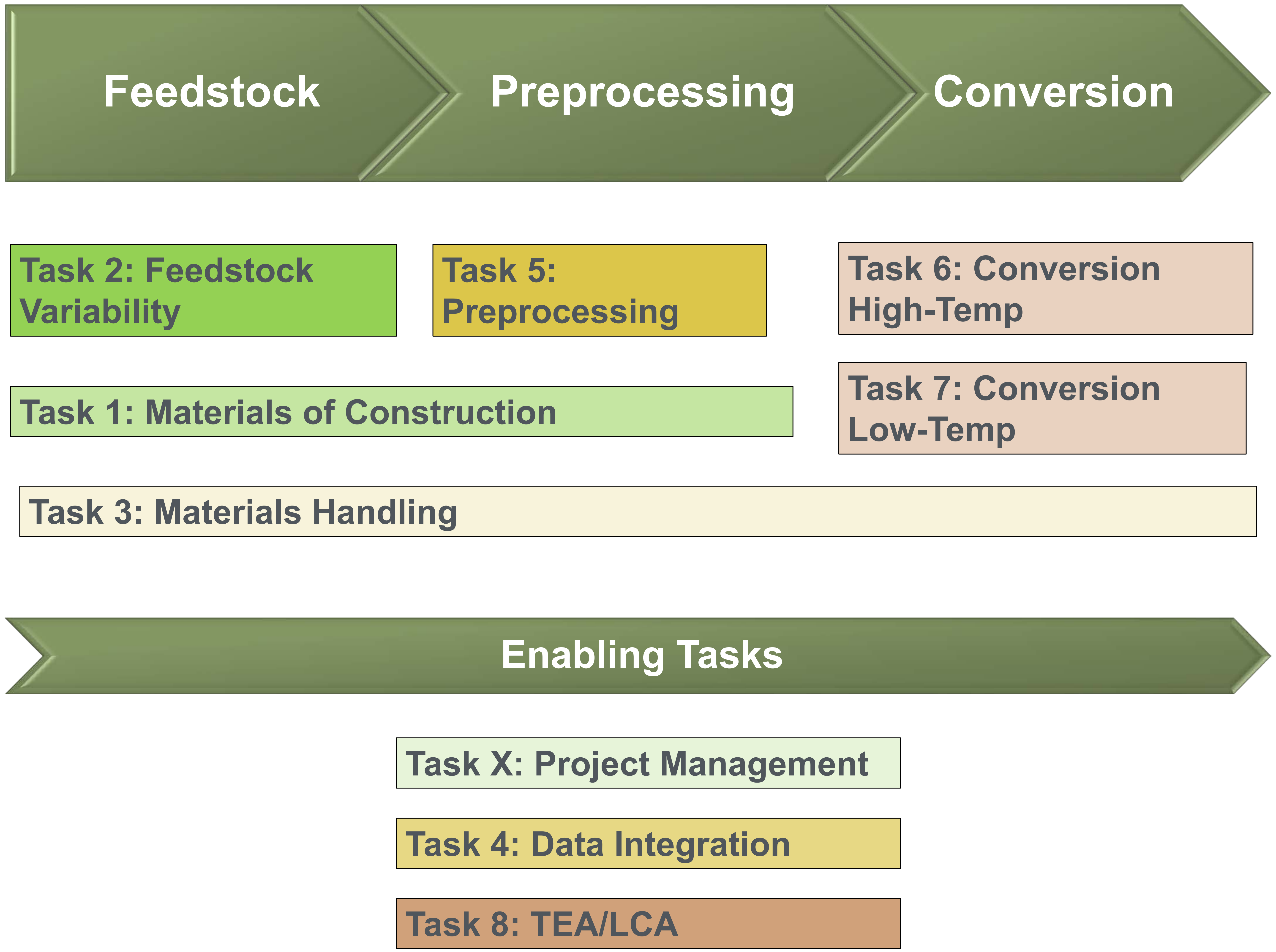
Key Ideas

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

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

http://energy.gov/fcic

FCIC Task Organization



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

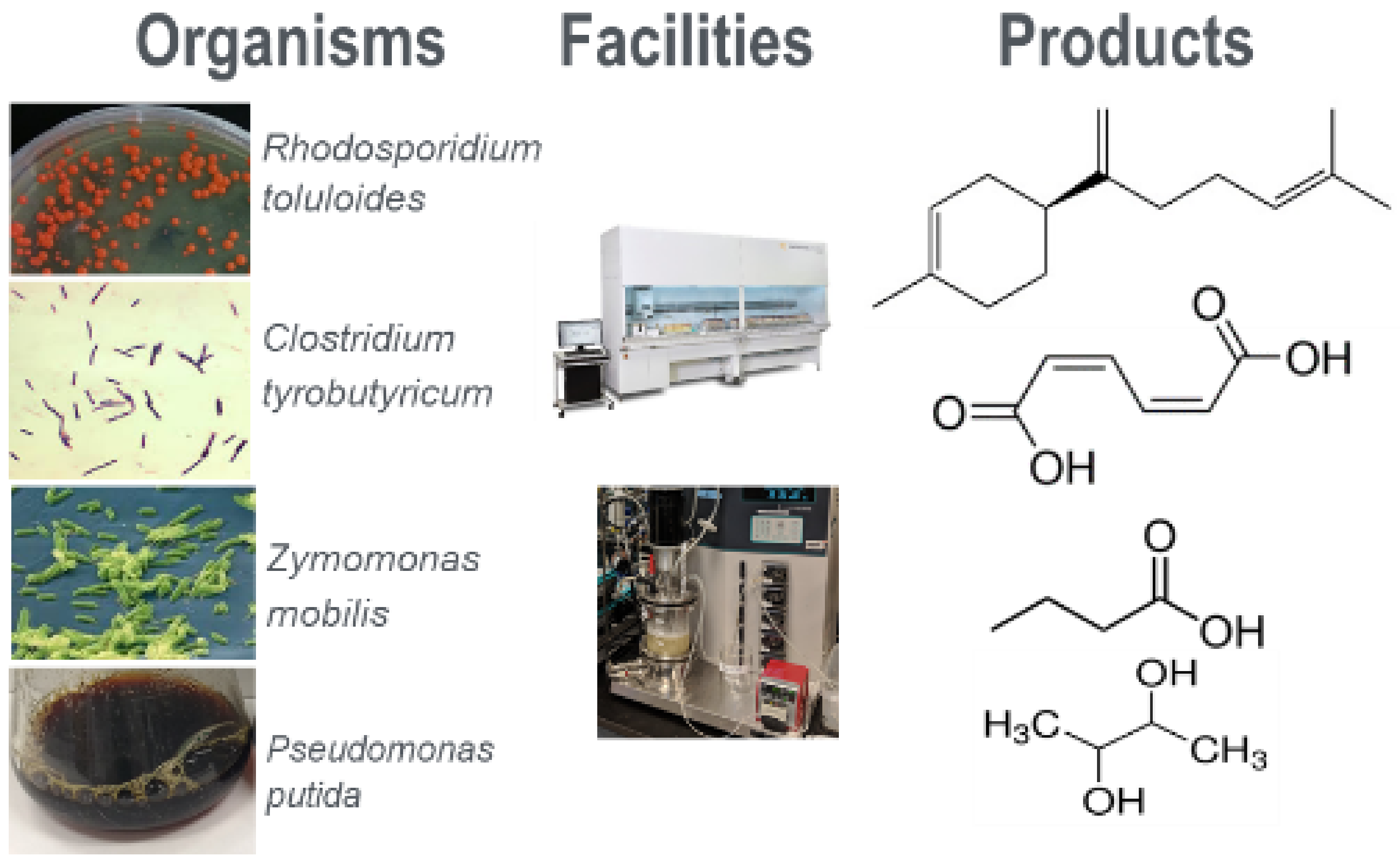
Task 6 & 7: Conversion (High- & Low-Temp Pathways): Produce homogeneous intermediates to convert into market-ready products

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

Quantifying Effects of Variability to Assess Risk

- An example using low-temperature conversion
  - Corn stover Feedstock
  - Deconstruction with Deacetylation & Mechanical Refining and Enzymatic Hydrolysis (DMR/EH)
  - Upgrading Sugars to mixed organic acids, lignin monomers to muconate

- **How does corn stover variability present a risk to biorefineries?**



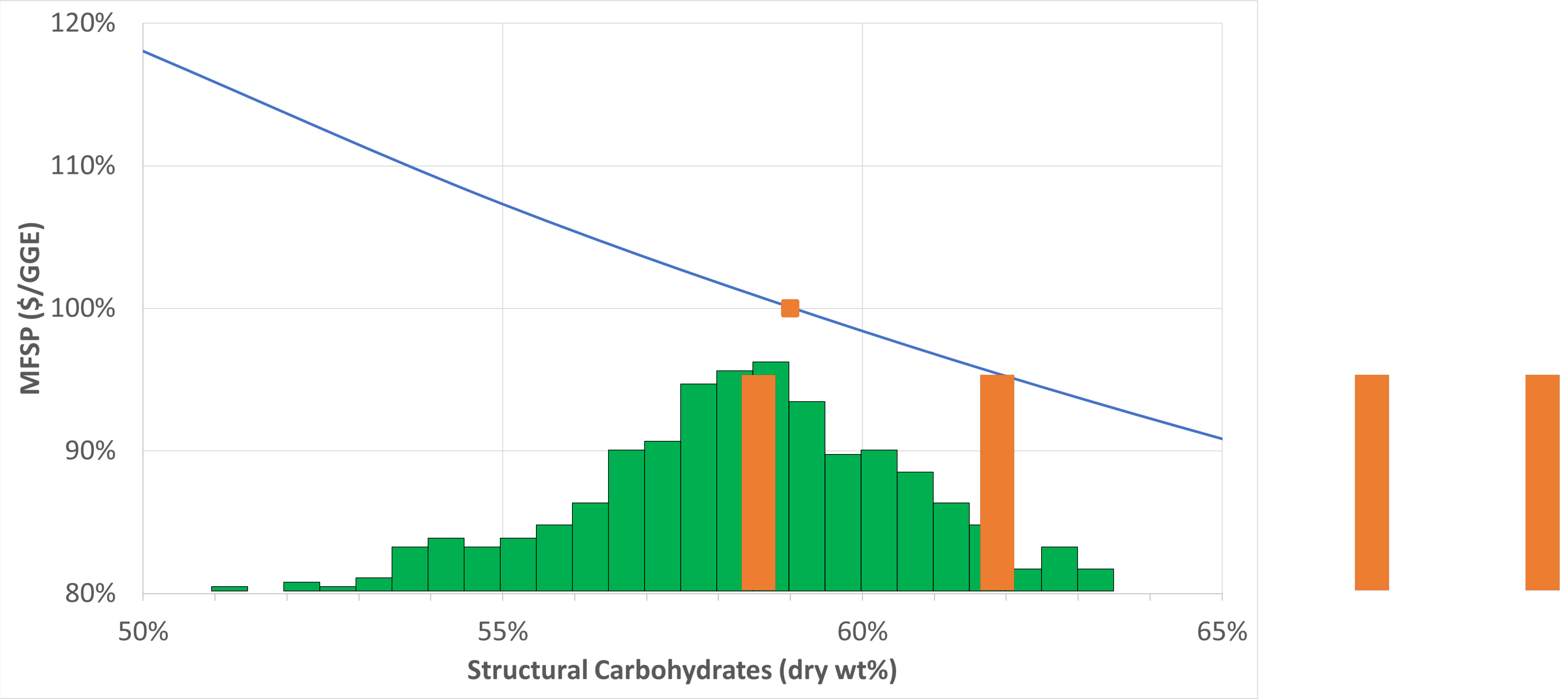
Feedstock Variability is an Economic Risk

COMPOSITION | COST | CONVERTIBILITY

Risk ~ slope and shape of the lines

Analysis courtesy of Ryan Davis (NREL)

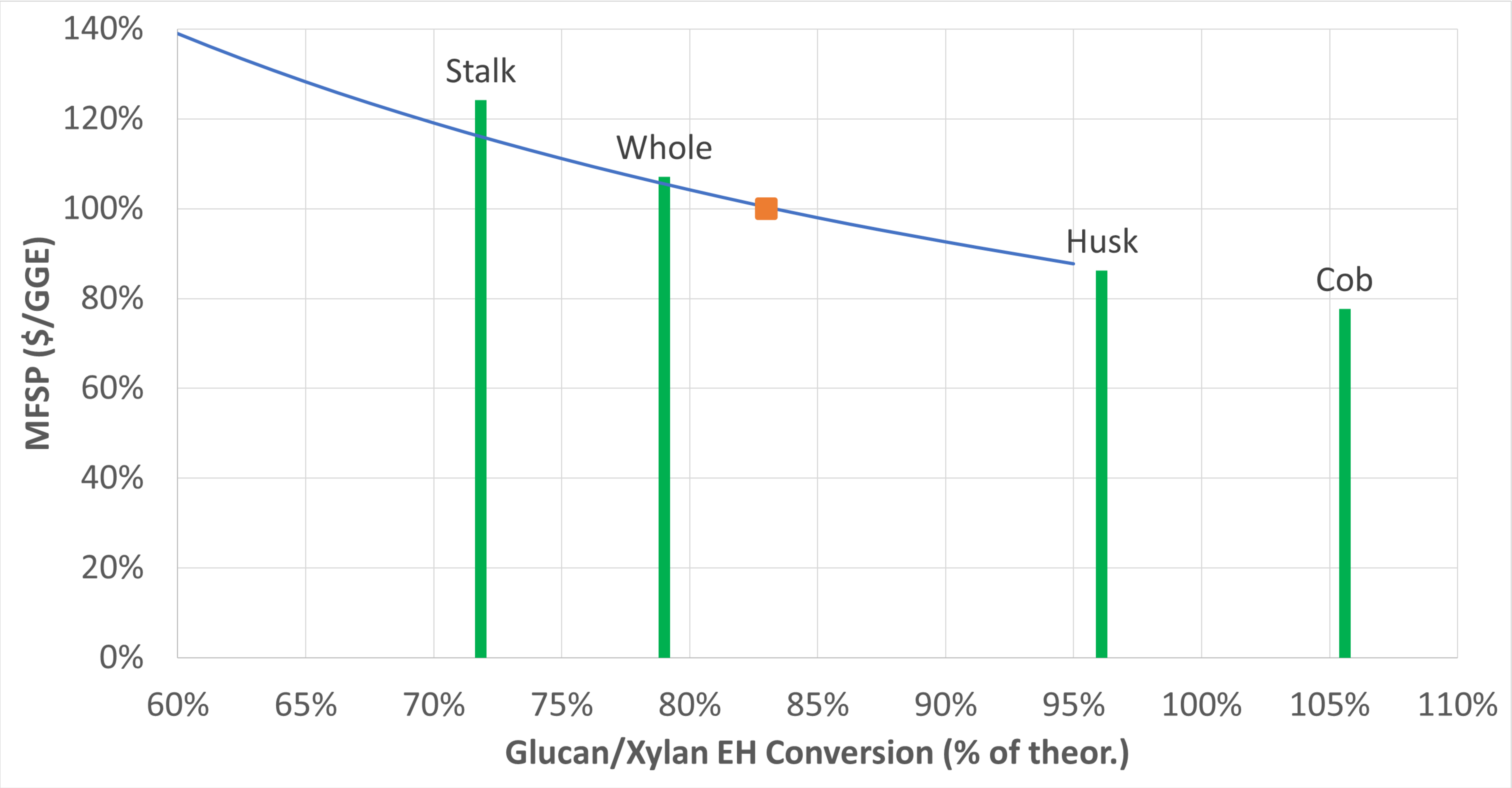
Composition Variability is a Risk



Data from reference below, analysis courtesy of Ryan Davis (NREL)

Effect of corn stover compositional variability on minimum ethanol selling price (MESP), *Bioresource Technology 140:426 (2013), Tao et al,* https://doi.org/10.1016/j.biortech.2013.04.083

Conversion Variability is a Risk



Data courtesy of Xiaowen Chen (NREL), analysis courtesy of Ryan Davis (NREL)

Quality by Design

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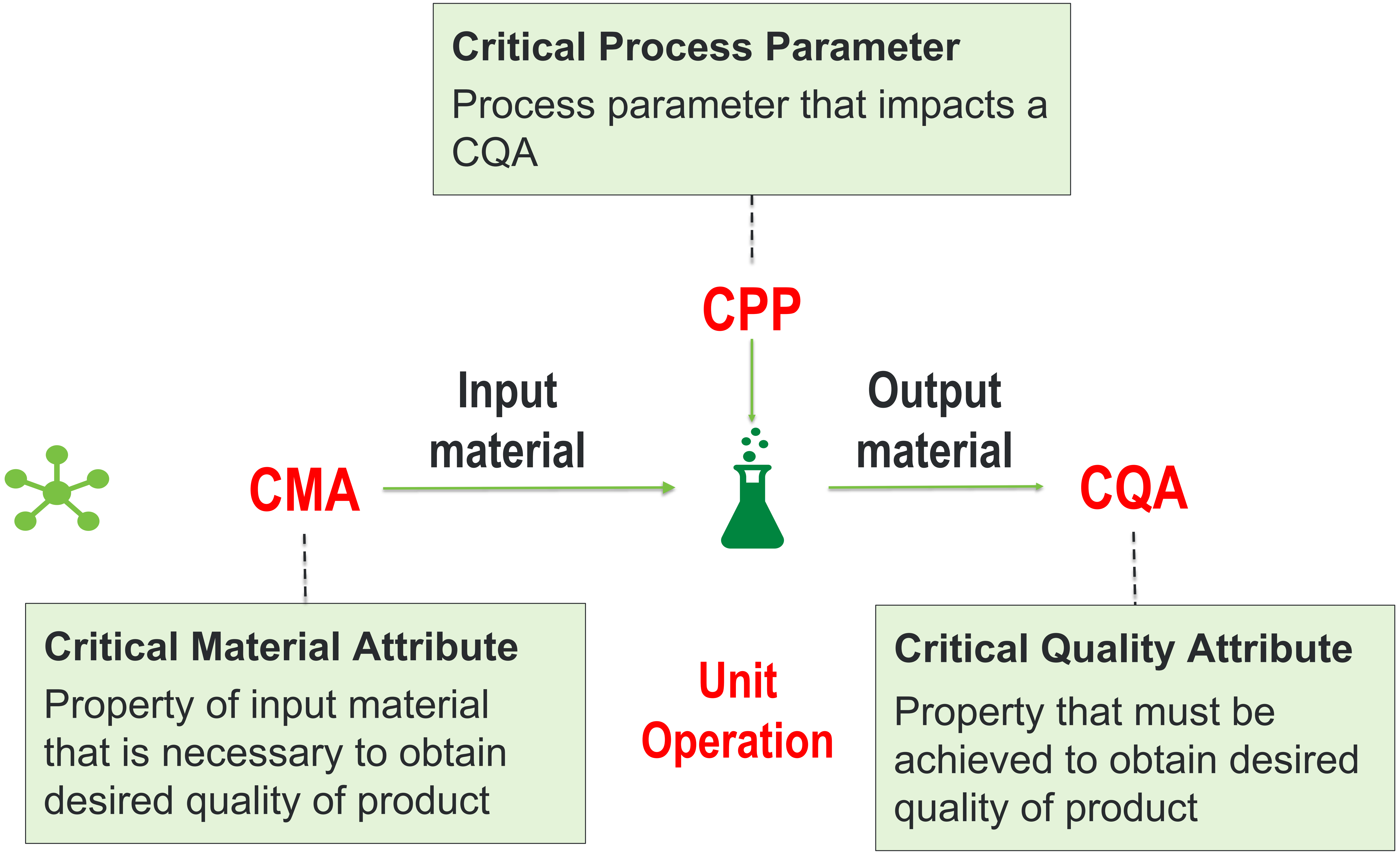
Quality by Design (QbD) to Assess Risk

- Key operating concept and organizing principle
- Widely used in pharmaceutical manufacturing – FDA-endorsed
- Chemical processes are collections of specific unit operations
- Unit operations are discrete but connected
- Need fundamental understanding of
  - Unit operation
  - Input & Output streams

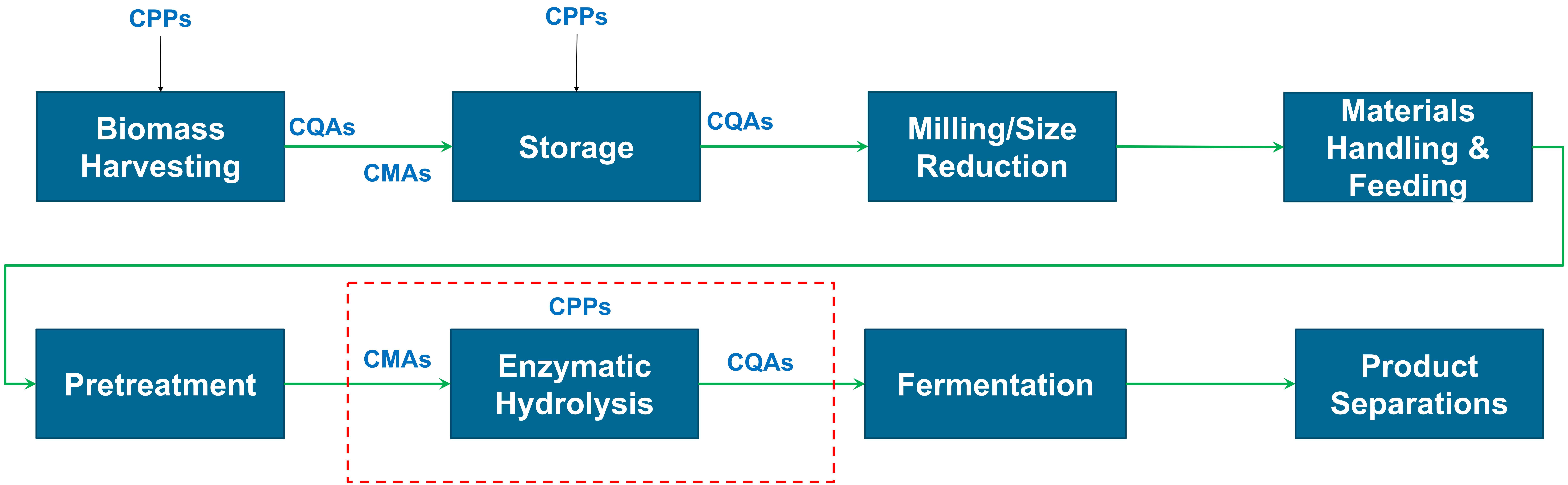


QbD is about Feedstock Attributes….

Moving from feedstock NAMES to feedstock ATTRIBUTES

hayandforage.com

QbD for the Biomass Value Chain



CMAs:
- **Structural Carbohydrate Content**
- **Digestibility**
- Inhibitors (e.g., pretreatment byproducts)

CPPs:
- Temperature
- Enzyme Loading
- Residence Time

- **CQAs**: Soluble Sugar Content
- Residual substrates
- Inhibitors

Representative Accomplishments

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Review Article: Flow Behavior Characterization of Biomass Feedstocks

Knowledge

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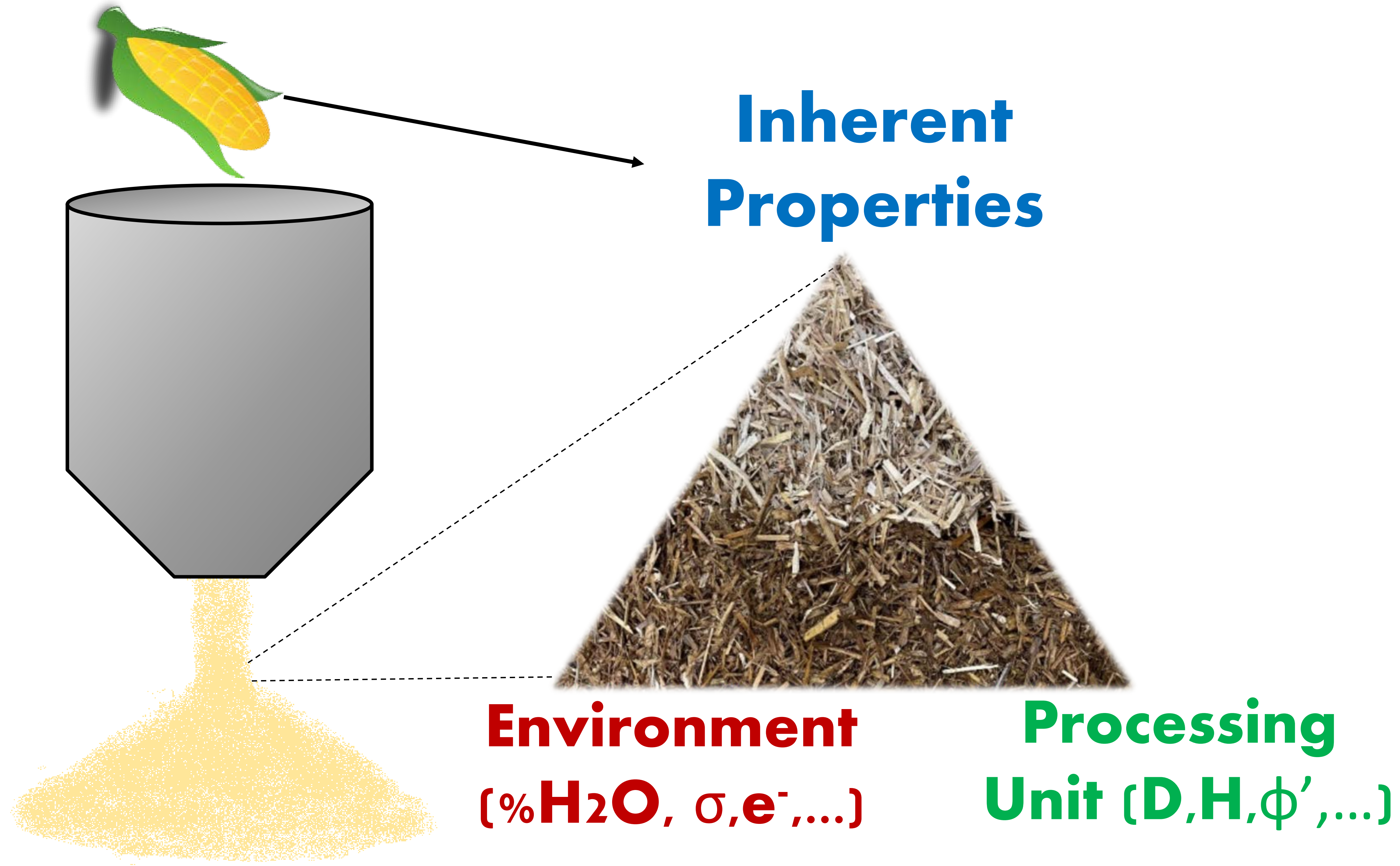
It's imperative to test each powder because the flow behavior of a powder is determined by its inherent properties, the environment, and the processing unit it's in.



Current Knowledge Gap

- Existing powder processing/handling equipment are mostly designed for coal and pharmaceutical ingredients, rather than for biomass
- Biomass encounters flow stoppages in these repurposed equipment, hampering process economics
- Lack of knowledge on the unique flow behavior of biomass feedstocks

Achievement

- **Discussed** how powder flow behavior depends on the inherent properties, the environment, and the processing equipment
- **Reviewed** literature on the characterization of biomass powder flow behavior using shear testers and powder rheometers
- **Proposed** complementing powder rheometry with surface energy measurements, tribometry and DEM modeling to better understand the flow behavior of biomass powders

Industry Impact

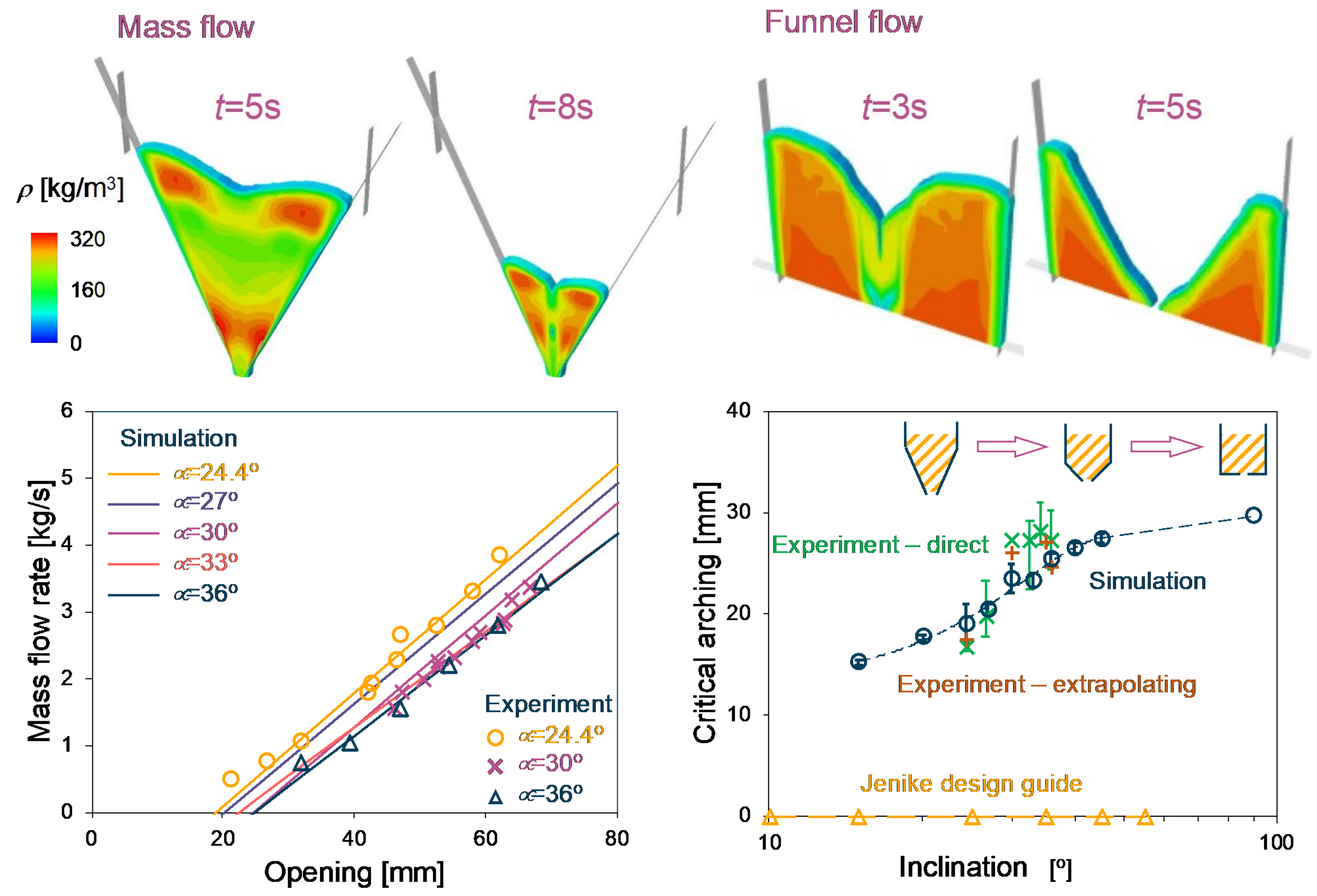
This review article educates audiences working on powder flow characterization in both industrial and academic settings, and provides them with insights on future research directions

Flow Behavior Characterization of Biomass Feedstocks. Powder Technology (2021) 387, 156-180, DOI: 10.1016/j.powtec.2021.04.004

Continuum Modeling of Hopper Flow

Knowledge

Investigated pine CMAs & Hopper CPPs on mass flow rate and critical arching width using experimental data validated continuum-model



Flow and Arching of Biomass Particles in Wedge-Shaped Hoppers, ACS Sustainable Chemistry & Engineering (2021) 9:45, 15303–15314, DOI:10.1021/acssuschemeng.1c05628

Current Knowledge Gap

- The mechanical flow behavior of compressible pine chips is not systematically investigated
- Flowing pine chips through hopper experiences inconsistence manifested as hopper arching, rat-holing, and surging flow

Achievement

- Conducted **physical experiments** and **numerical simulations** to investigate the influence of pine CMAs and hopper CPPs on hopper flow performance.
- Found hopper outlet width linearly controls the mass flow rate while the hopper inclination angle controls the critical outlet size.
- Found feedstock initial packing determines whether the flow is smooth or surging, and the surcharge-induced compaction creates flow impedance.

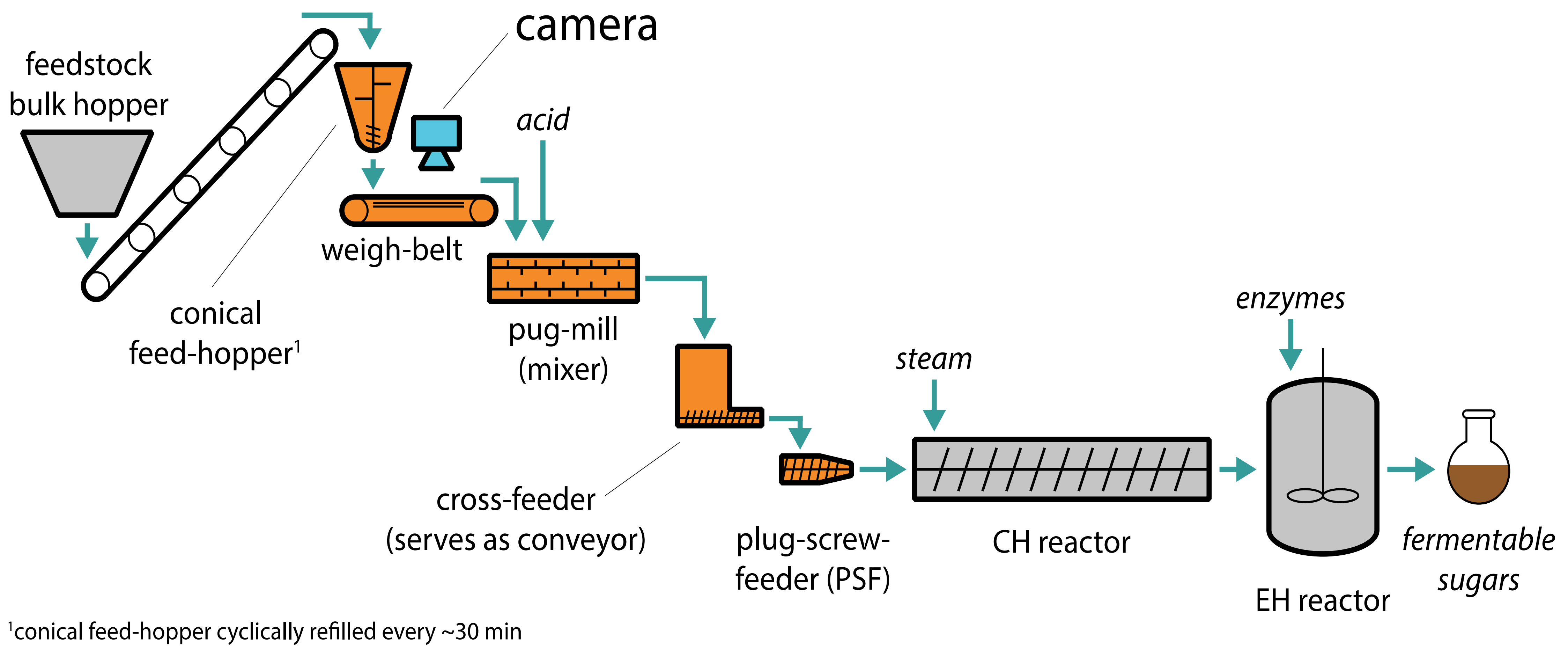
Industry Impact

- The knowledge can be directly applied to prepare the charging process of wedge-shaped hopper and to operate hopper in terms of inclination angle and outlet opening for handling pine chips.

Real-Time Feedstock Image Analysis Model

Tools

Automated machine vision technique detects and quantifies corn stover feedstock particle quality in real-time to enable process control



[1]conical feed-hopper cyclically refilled every ~30 min

Description

- Utilized a 26,000 image dataset from processing corn stover in a pretreatment reactor captured using **inexpensive digital cameras**.
- Machine Learning Methods - Neural Network (NN) and Pixel Matrix Feature Parameterization (PMFP) used to analyze data

Value of new tool

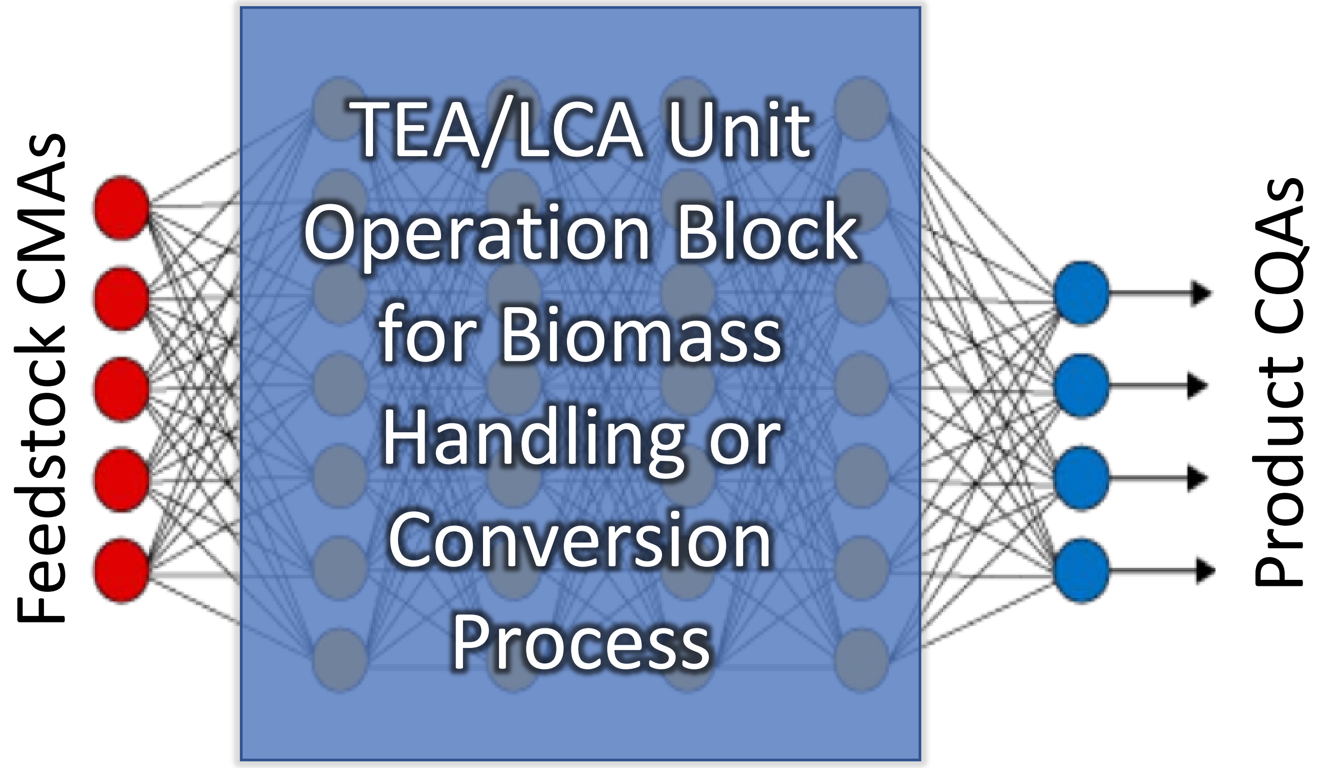
- Neural Network (NN) model can detect anomalies (coarse-particle segregation that can cause feed interruption) even when camera lens obscured by dust.
- PMFP method reveals statistically significant image textural features such as surface roughness, shade variations, and particle angular direction variations that are proxies for particle size distribution variation.
- NN and PMFP approaches are complementary to one another and can describe why feedstock images are classified a certain way.

Real-Time Biomass Feedstock Particle Quality Detection Using Image Analysis and Machine Vision. http://dx.doi.org/10.1007/s13399-020-00904-w

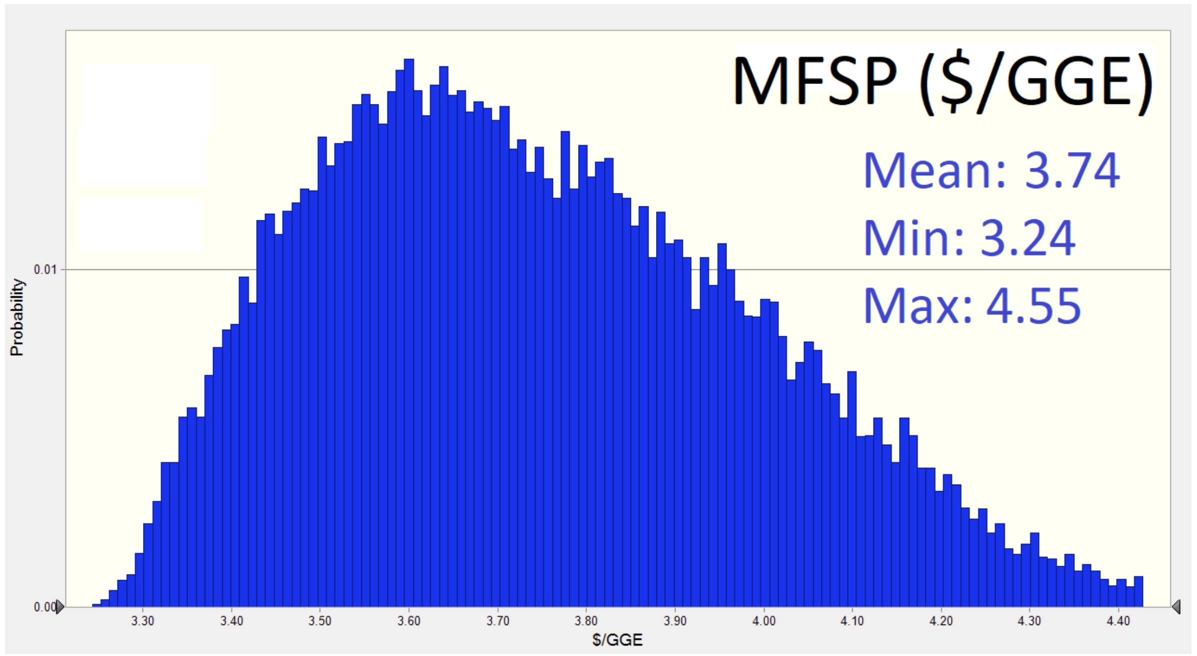
Computational Framework For High-Temperature Modeling – CFD to TEA

Tools

Combining Particle-, Reactor-, and Process models facilitates rapid TEA assessments of feedstock and process variability



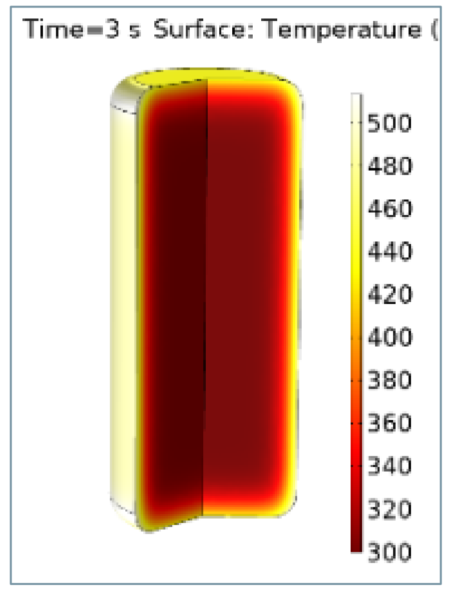
Output MFSP

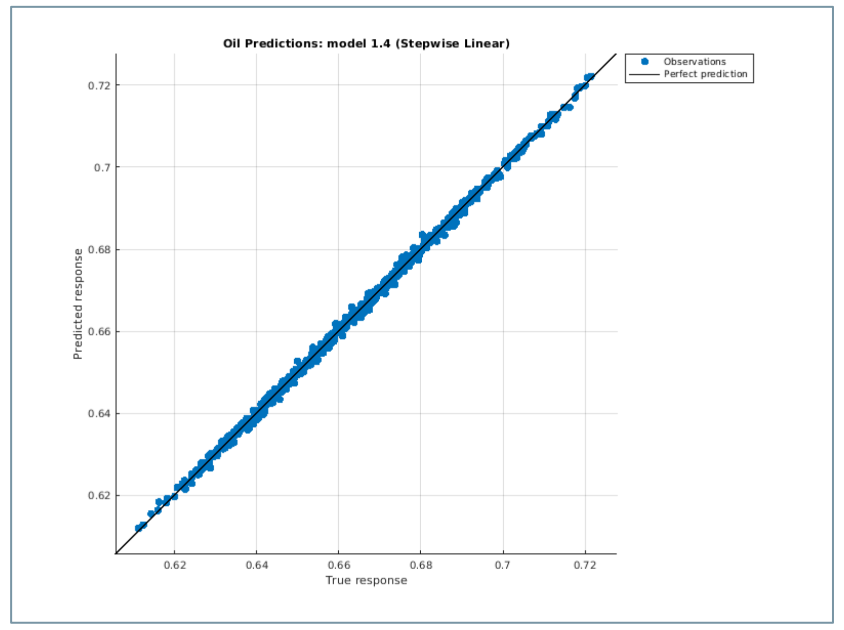


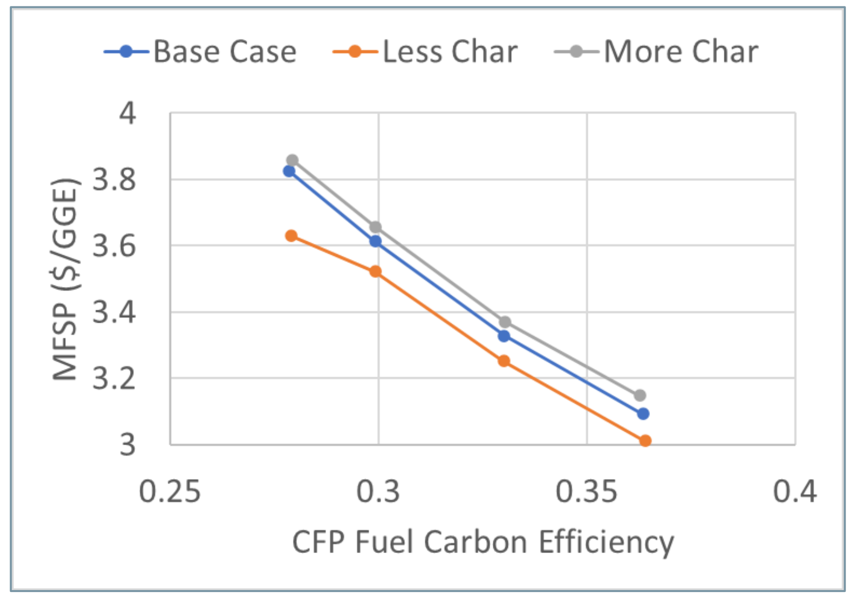
Machine learning (ML) style regression analysis develops correlations for evaluation in process modelling software (e.g., Aspen Plus)

MFSP Distribution

- mineral matter content
- moisture content
- particle size
- extractives content
- reactor temperature







Monte-Carlo Simulation

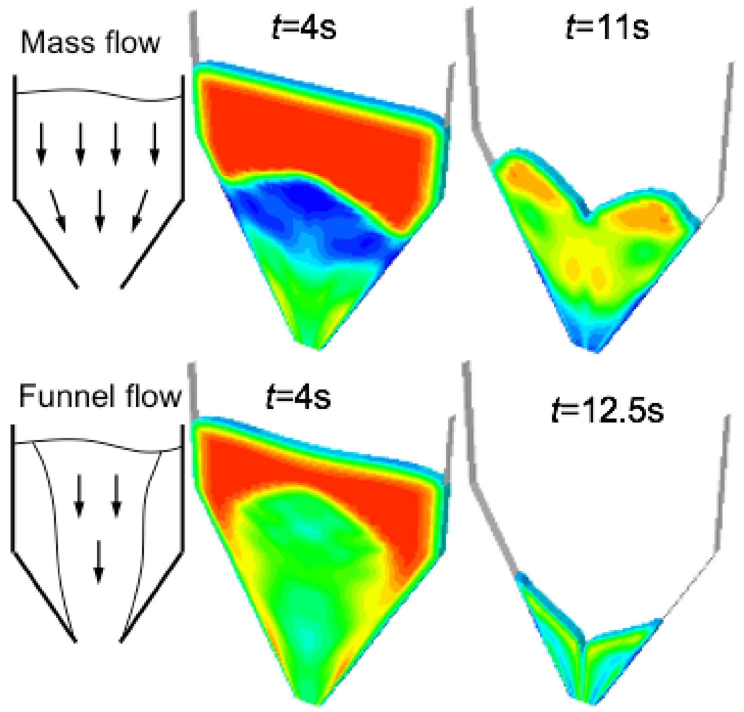
Validated Particle-Scale Model → **Multiple Linear Regression Models** → **Link with MFSP from CFP TEA models**

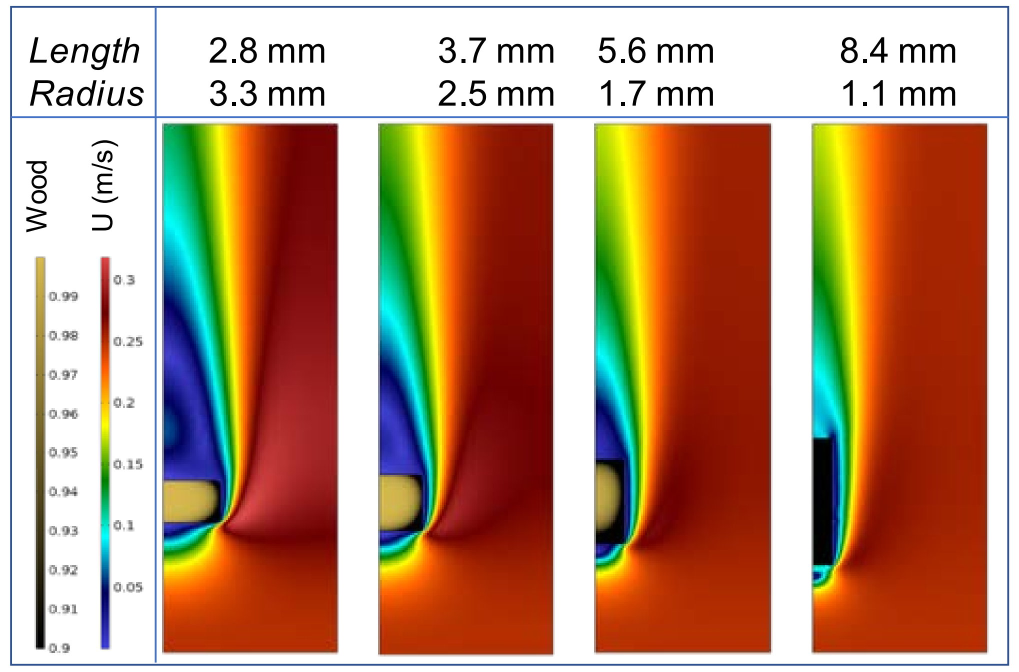
A simplified integrated framework for predicting the economic impacts of feedstock variations in a catalytic fast pyrolysis conversion process https://doi.org/10.1002/bbb.2319

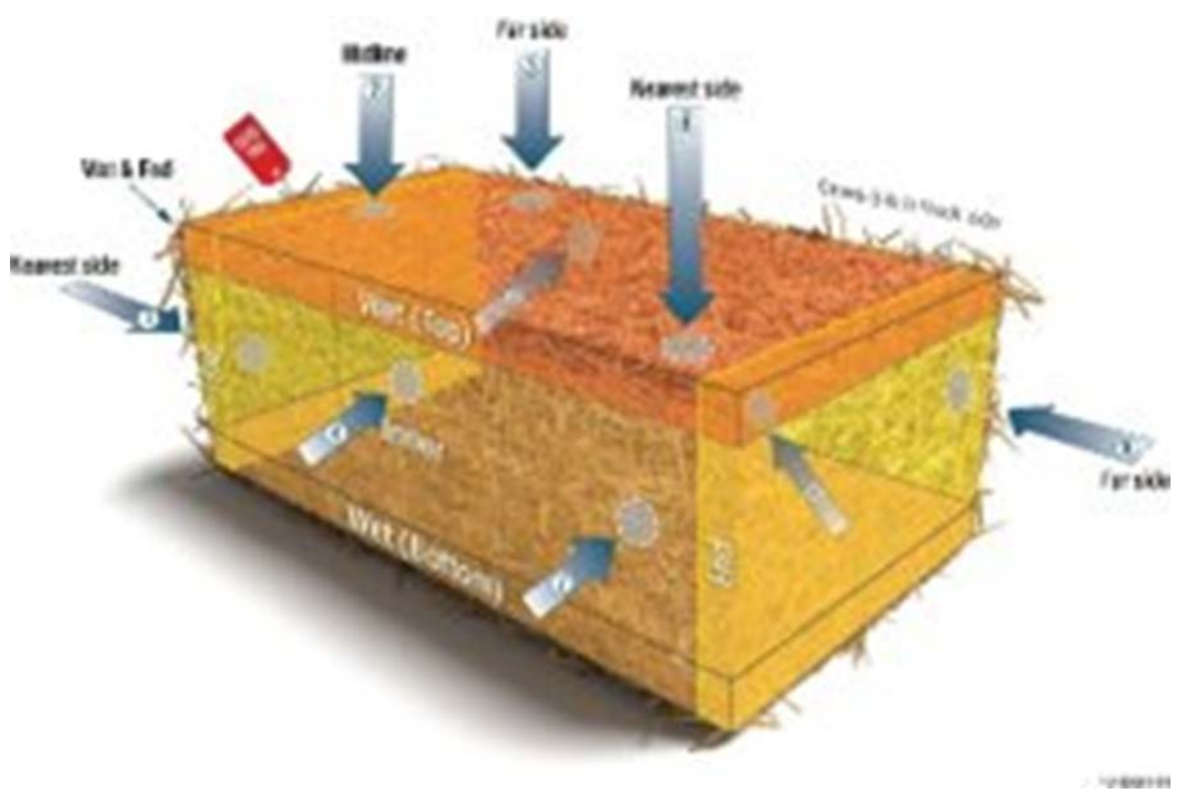
MFSP: Minimum Fuel Selling Price; **FP**: Fast Pyrolysis; **CFP**: Catalytic Fast Pyrolysis;
TEA: Techno-Economic Analysis

Key Take-Aways

- **Feedstock variability** across the Bioenergy Value Chain is a Risk to Biorefineries
- **FCIC** Researchers are using elements of the **Quality-by-Design** approach to understand and mitigate the impacts of **feedstock variability** on bioenergy conversion processes.
- Deep subject matter expertise, detailed chemical, physical, and mechanical characterization, and robust and validated modeling is providing **knowledge and tools** to bioenergy stakeholders







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fcic@nrel.gov

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