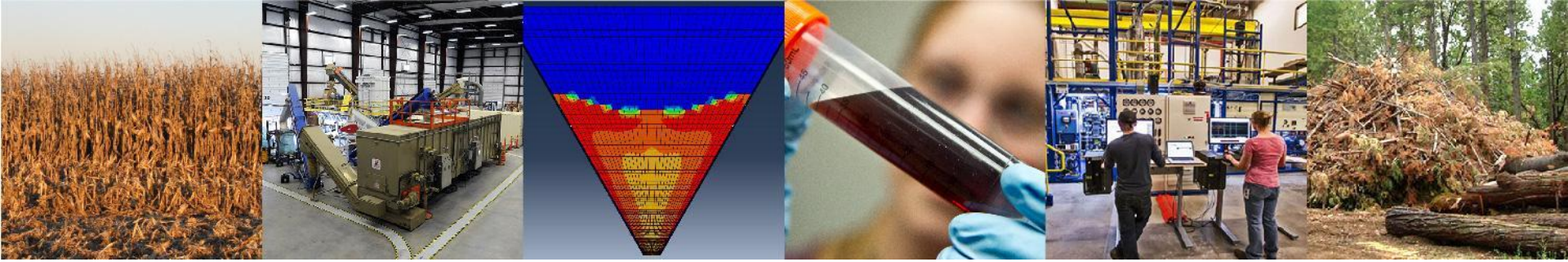

Providing Innovative Solutions to Address Operational Challenges Faced by Biorefineries

Sandia National Laboratories

Argonne NATIONAL LABORATORY

INL Idaho National Laboratory

Pacific Northwest NATIONAL LABORATORY

DEPARTMENT OF ENERGY · UNITED STATES OF AMERICA ·

BERKELEY LAB Lawrence Berkeley National Laboratory

OAK RIDGE National Laboratory

Los Alamos NATIONAL LABORATORY EST. 1943

NREL NATIONAL RENEWABLE ENERGY LABORATORY

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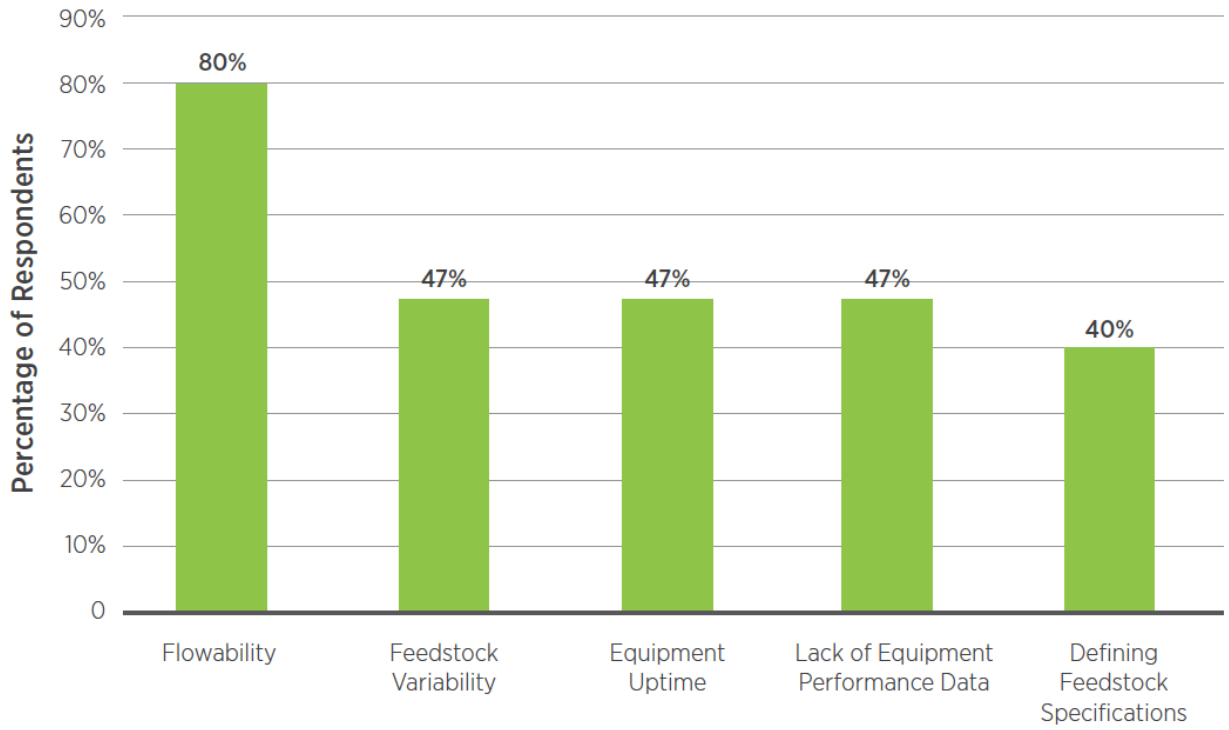
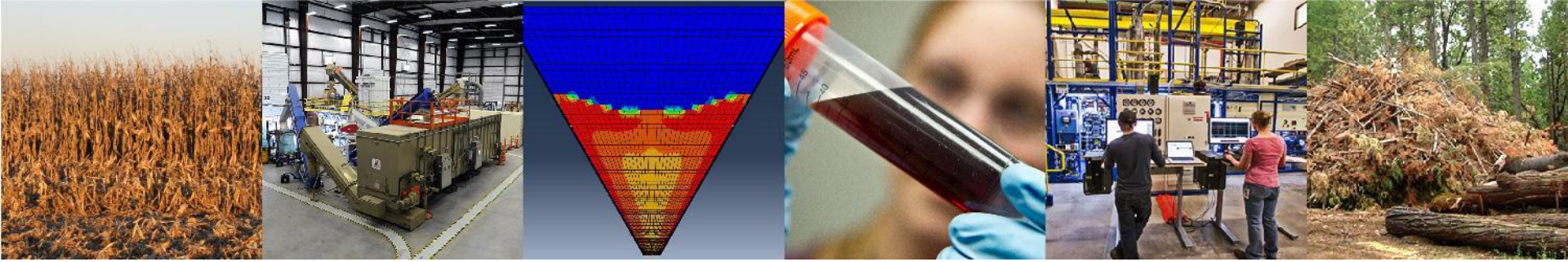
Motivation for FCIC

#1 issue plaguing High and Low Temperature Integrated Biorefinery (IBR) projects is **inconsistent operability** of preprocessing and primary deconstruction



BETO Biorefinery Optimization Workshop summary report (2016)



Goal of the Consortium

Identify and address the impacts of feedstock variability - chemical, physical, and mechanical – on biomass preprocessing and conversion equipment and system performance, to move towards 90% operational reliability.

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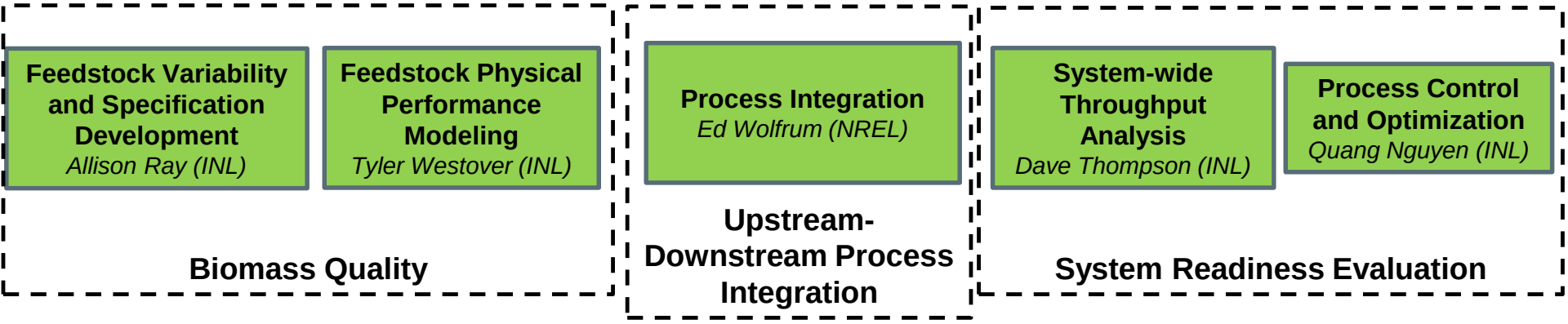
FCIC Pillars of Success



Characterizing Biomass & Mining Data

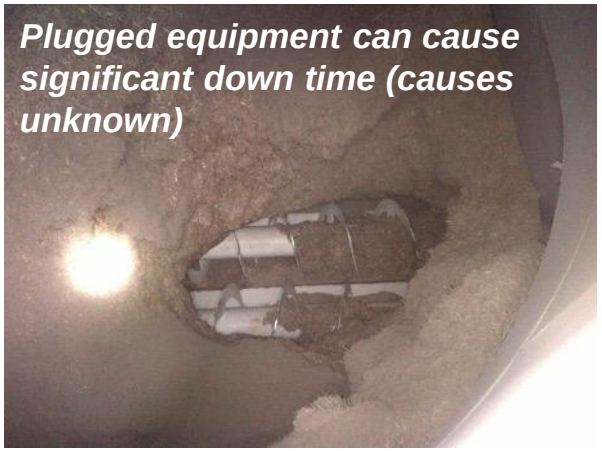
Improving Operational Performance

Implementing Integrated Control Strategies

Feedstock-Conversion Interface Aims to Address Challenges

Opportunities

- Establish Specs. in feedstocks and intermediates
  - Physical, mechanical and chemical properties
- Quantify the impacts caused by biomass variability on equipment and conversion yield/quality
- Develop mechanistic models, process design tools for scaling transfer functions
- Compare preprocessing methods



Plugged equipment can cause significant down time (causes unknown)

Near Term Feedstocks

Harvest Practices

Biomass Variability Leads to Feed Handling & Conversion Inconsistencies

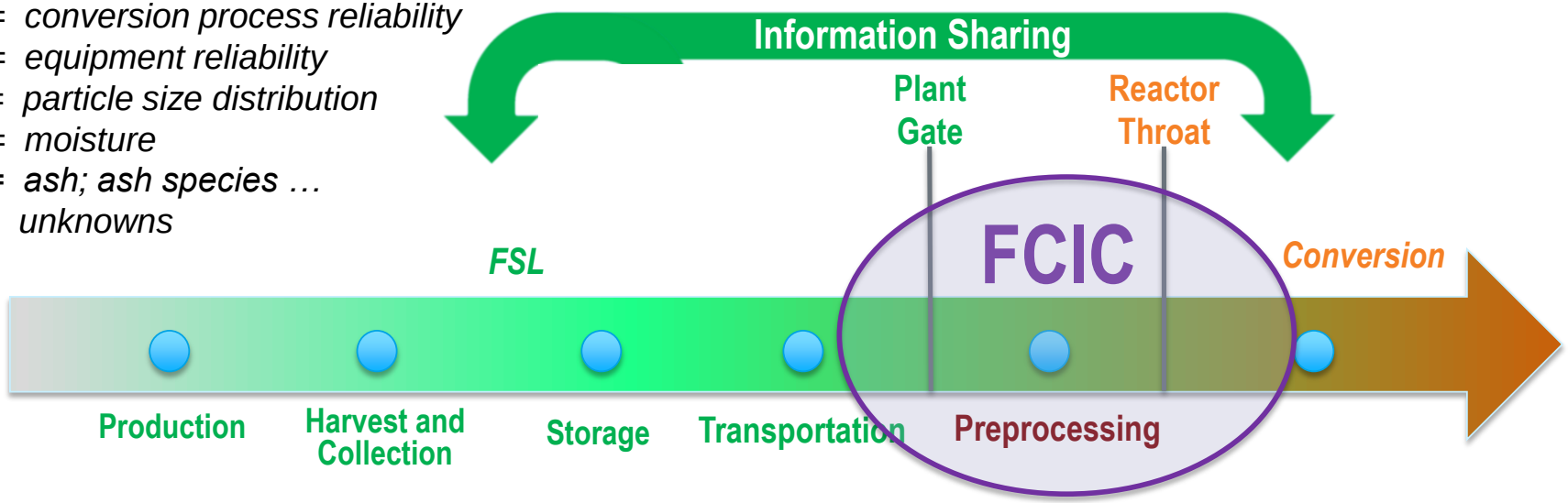
- Biomass Variability
  - Chemical Composition
  - Physical and Mechanical Properties
  - Cell Wall Architecture
  - Others…
- Sources of Variability
  - Agronomic/Field Management
  - Geospatial Events (soil type, weather, etc.)
  - Harvest & Collection Processes
  - Storage Operations (+ aging)
  - Preprocessing Techniques
  - Genetics
  - Others….
- Compounded by handling and preprocessing equipment designed for other purposes.

FCIC Rationale and Focus

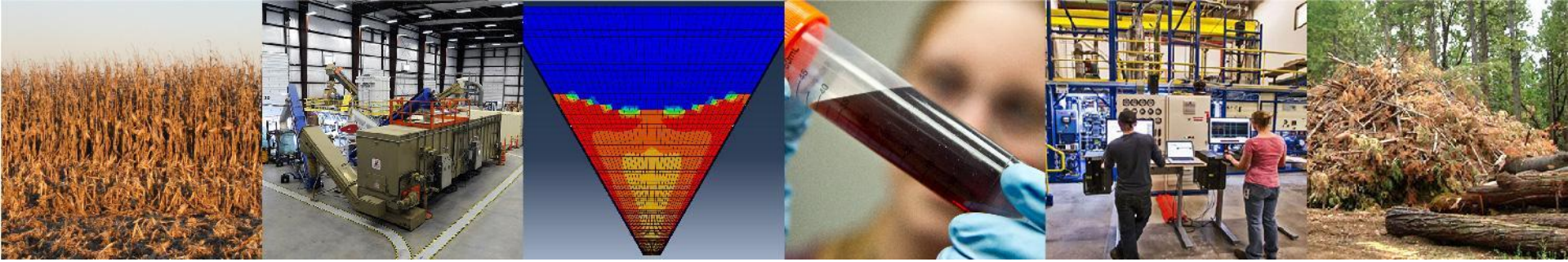
Guiding Principle: Feedstock chemical, physical and mechanical characteristics are primary considerations for process development, scale-up, and integration.

> 90% Operating Reliability = f (x, y, z, w, v… ø)

x = feedstock supply chain reliability
y = conversion process reliability
z = equipment reliability
w = particle size distribution
v = moisture
… = ash; ash species …
ø = unknowns



Why now? Early-stage applied research is currently the gap in enabling scalability and maximizing yields.



FY2018 FY2019 FY2020+

Baseline → Fundamental Understanding → Mitigation → Implementation

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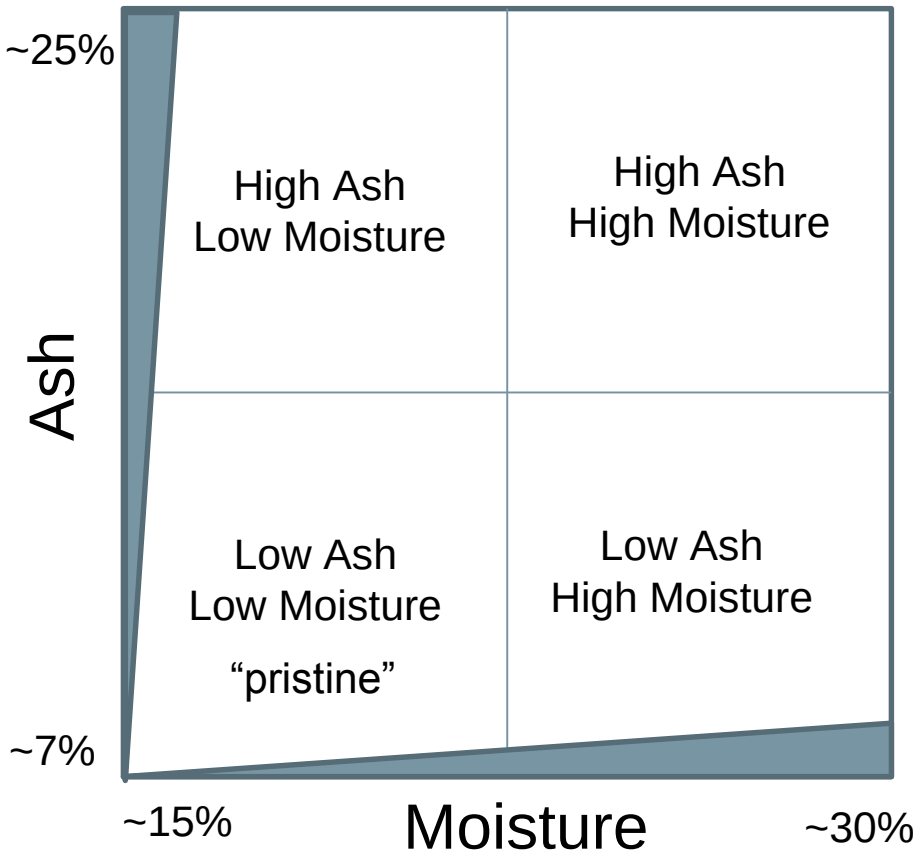
Corn Stover Feedstocks

Low Temperature Baseline Tests

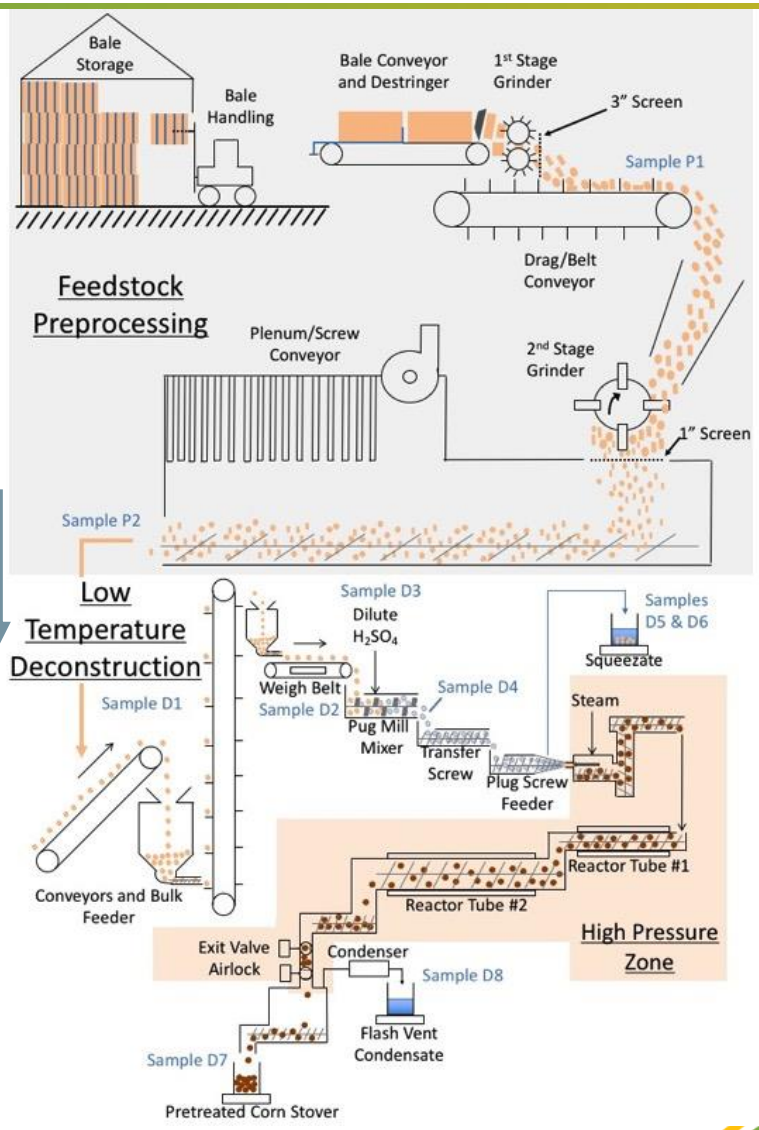
- Secured ~34 bales for each of 4 conditions
- Multi-pass harvest in IA 10/2018 adjacent to Project Liberty Plant
- Stored field-side, experienced rain events prior to final storage
- In storage at Iowa State, pending delivery to INL



Low-Temperature Primary Deconstruction

INL

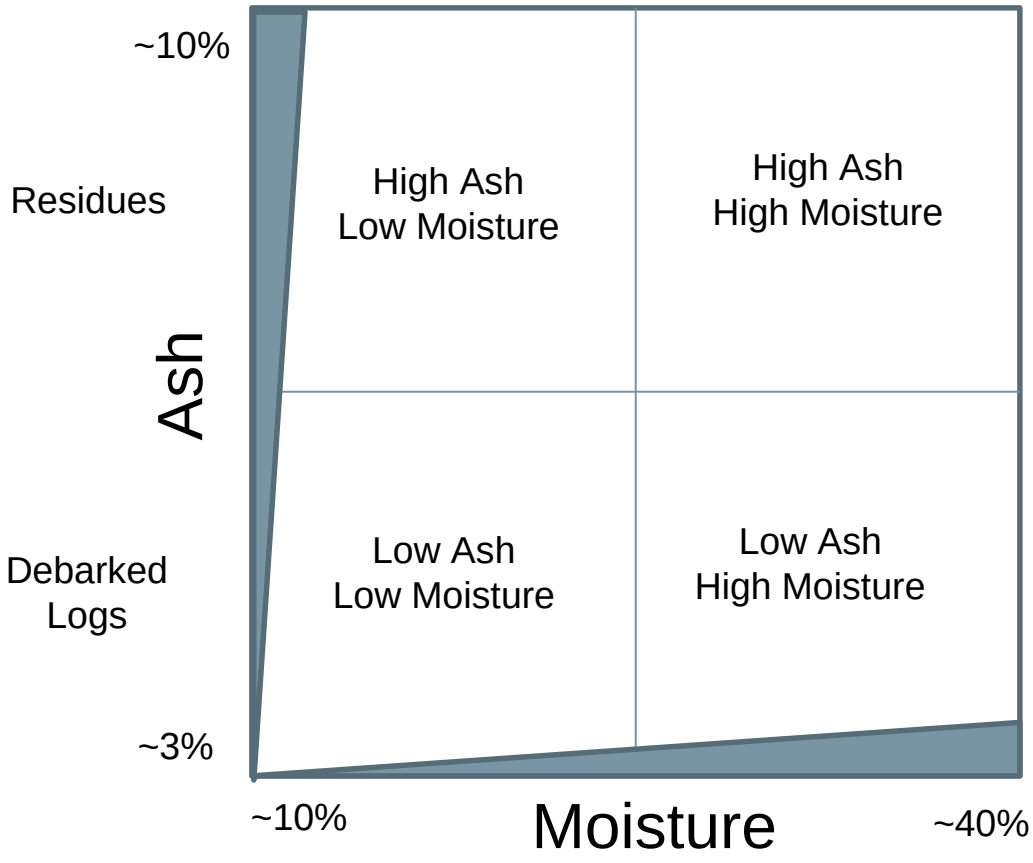
NREL



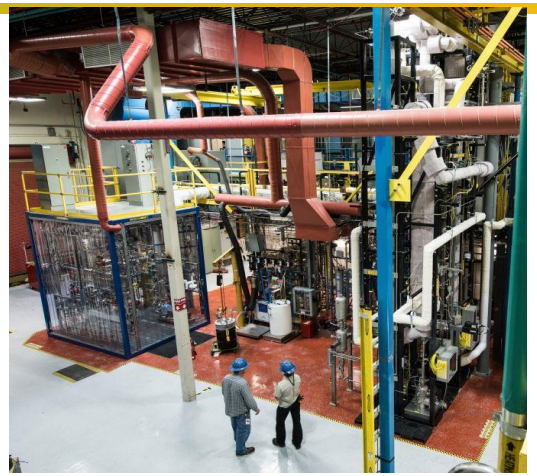
Pine Feedstocks

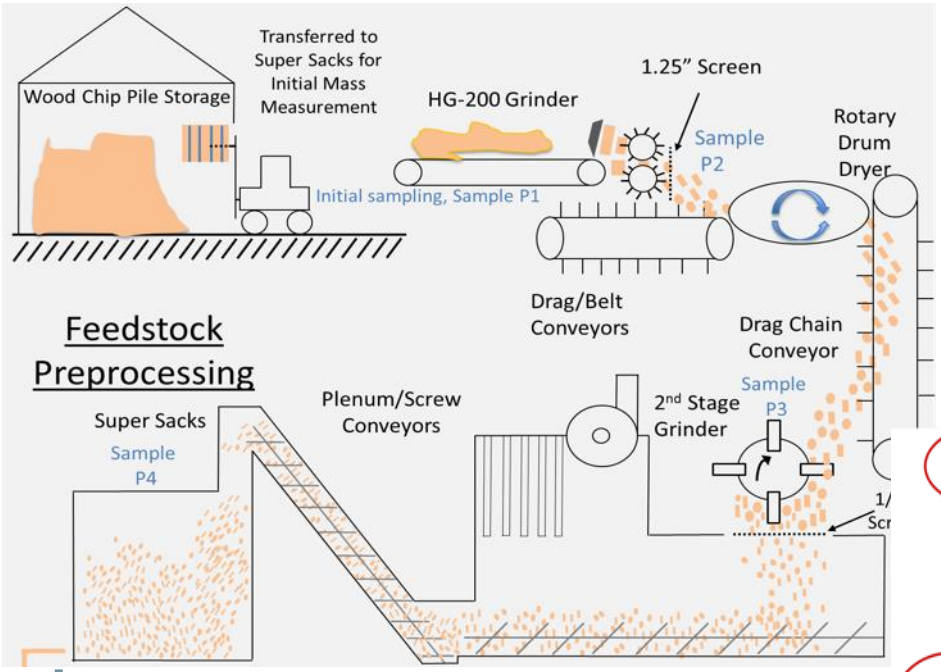
High Temperature Baseline Tests

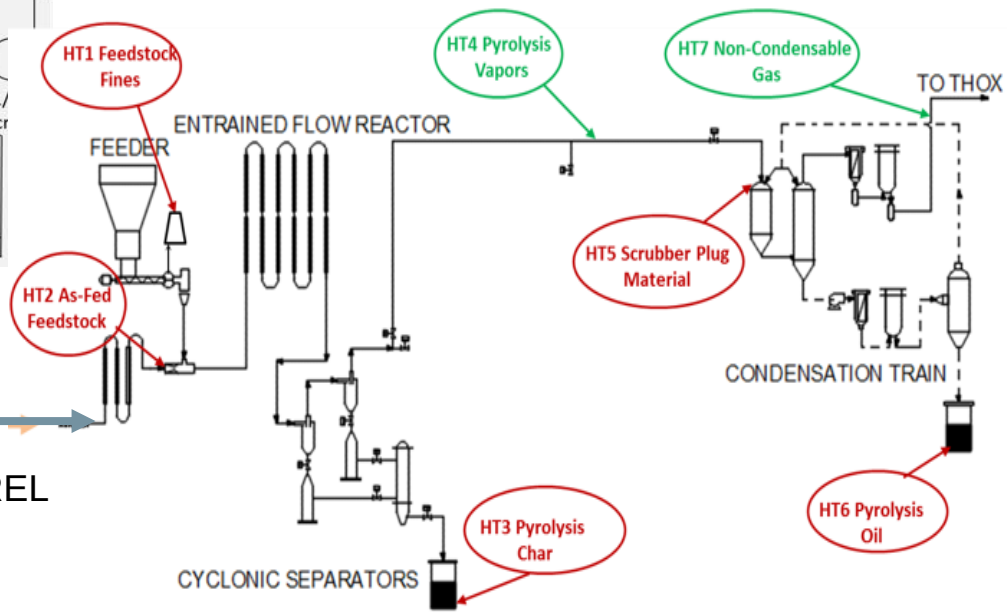
- 11-25 years of age from Georgia pine plantation
- Harvest equipment (Feller buncher, grapple skidder and disc chipper w/ or w/o flail chains).
- chipped to 2” nominal at the field then shipped to INL.



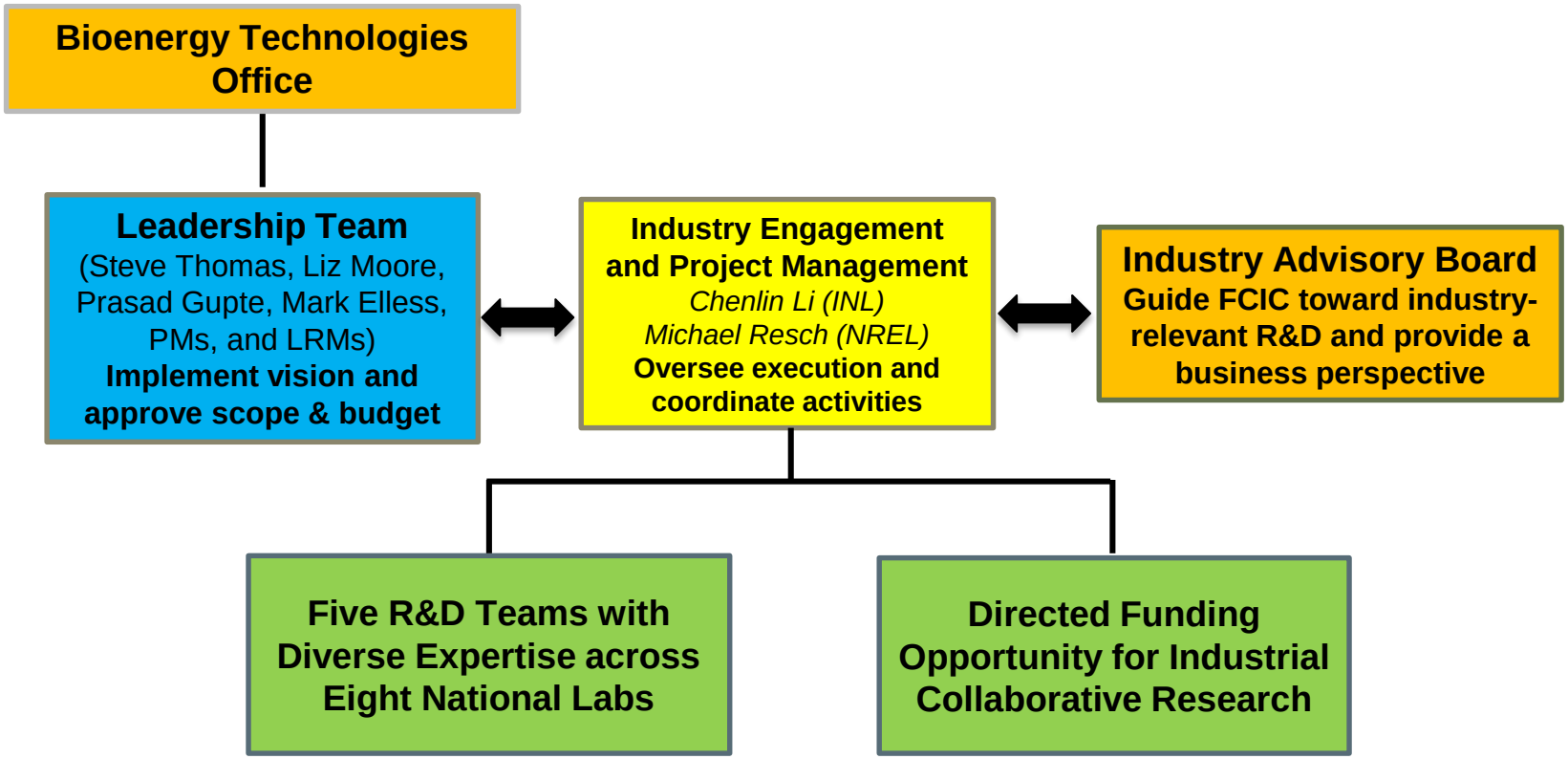
High-Temperature Primary Deconstruction







FCIC Organization Chart



Outcome: detailed understanding of the physics and chemistry of each feedstock and preprocessing step necessary for high conversion yeilds

Approach – Management

Chenlin Li (INL)

Kevin Kenney (INL)

Zia Abdullah (NREL)

Corinne Drennan (PNNL)

Katy Christiansen (LBNL)

Michael Resch (NREL)

Tim Theiss (ORNL)

Babetta Marrone (LANL)

Paul Bryan (SNL)

Meltum Urgun Demirtas (ANL)

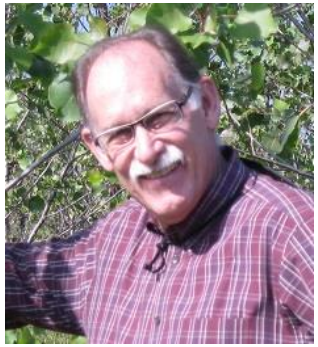
Leadership Team

BETO Team FY18

BETO Director
Jonathan Male

Feedstock Supply Logistics Program

Program Manager
Alison Goss Eng



Technology Manager
Steve Thomas

Acting Program Manager /
Technology Manager
Mark Elless

Conversion Research and Development Program

Program Manager
Kevin Craig

Technology Manager
Prasad Gupta

Advanced Development and Optimization Program

Program Manager
Jim Spaeth

Technology Manager
Liz Moore

BETO Team FY19

BETO Director
Jonathan Male

Feedstock Supply Logistics Program

Program Manager
Alison Goss Eng

Technology Manager
Mark Elless

Conversion Research and Development Program

Program Manager
Kevin Craig

Lead FCIC Technology Manager
Beau Hoffman

Advanced Development and Optimization Program

Program Manager
Jim Spaeth

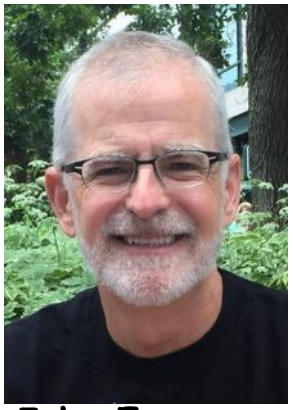
Technology Manager
Liz Moore

FCIC Industry Advisory Board Members

Ravi Chandran
(TRI)

William Crump
(Leidos)

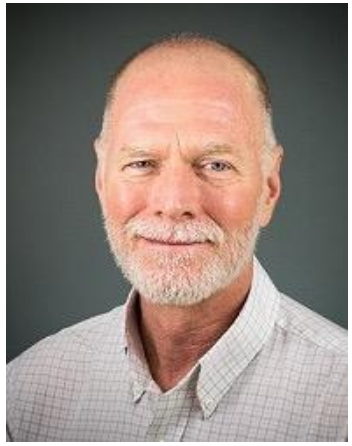
Brandon Emme
(ICM)



John Evans
(AB Biotek)

Glenn Farris
(AGCO)

Reddy Karri
(PSR)



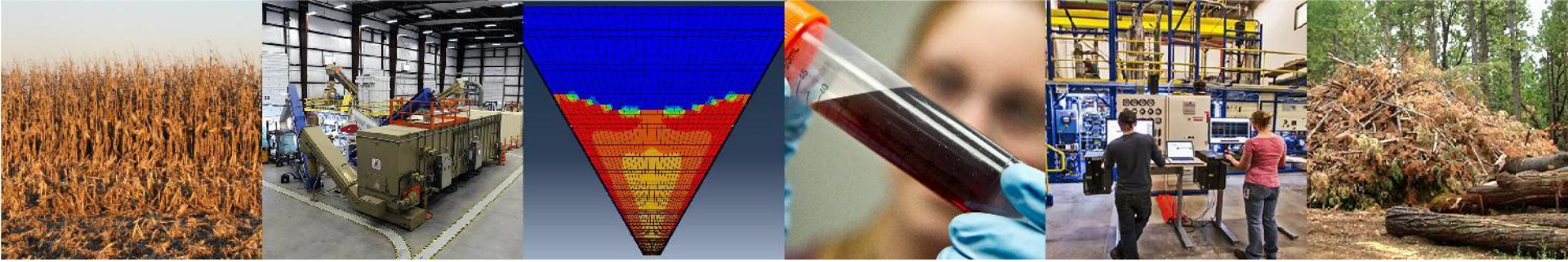
Steve Kelley
(NC State)

Tom Miles
(TR Miles Consulting)

Directed Funding Opportunity

- **$8 Million available for Industry/ National Lab Partnerships**
  - Additional required 30% non-federal cost share (in-kind &/or cash)
- Promoting industry/lab collaborative R&D (TRL 2-6)
  - To attract capabilities from
    - National Laboratories
    - Academia
    - Bioenergy and bioproducts Industry

- Topics align with the three FCIC pillars:
  1. Biomass Quality
  2. Process Integration
  3. Techno-economic Analysis and Process Control Development



Feedstock Variability and Specification Development
Allison Ray (INL)

Feedstock Physical Performance Modeling
Tyler Westover (INL)

Biomass Quality

Process Integration
Ed Wolfrum (NREL)

Upstream-Downstream Process Integration

System-wide Throughput Analysis
Dave Thompson (INL)

Process Control and Optimization
Quang Nguyen (INL)

System Readiness Evaluation

Characterizing Biomass & Mining Data

Improving Operational Performance

Implementing Integrated Control Strategies

Allison Ray, Rachel Emerson, Amber Hoover, Jordan Klinger, Tyler Westover, Luke Williams, Magdalena Ramirez-Corredores (INL)
Deepti Tanjore (LBNL)
Troy Semelsberger (LANL)
Erin Webb (ORNL)
Bryon Donohoe, Nick Nagle, Ed Wolfrum (NREL)
Kenneth Sale (SNL)

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FEEDSTOCK-CONVERSION INTERFACE CONSORTIUM

Feedstock Variability and Specification Development

History:

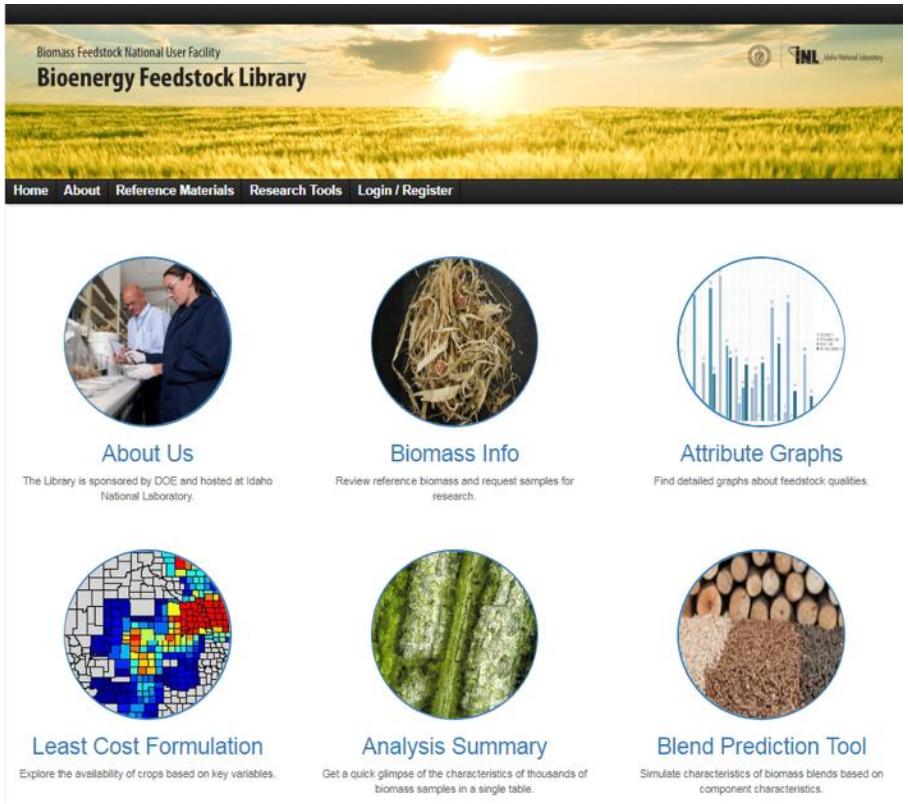
- Lack of feedstock historical information in literature nor from IBRs

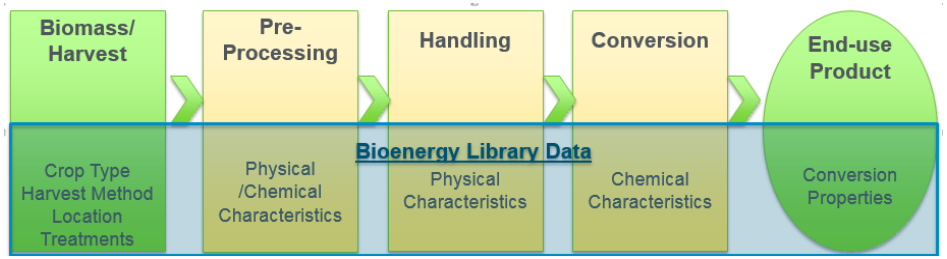
Approach

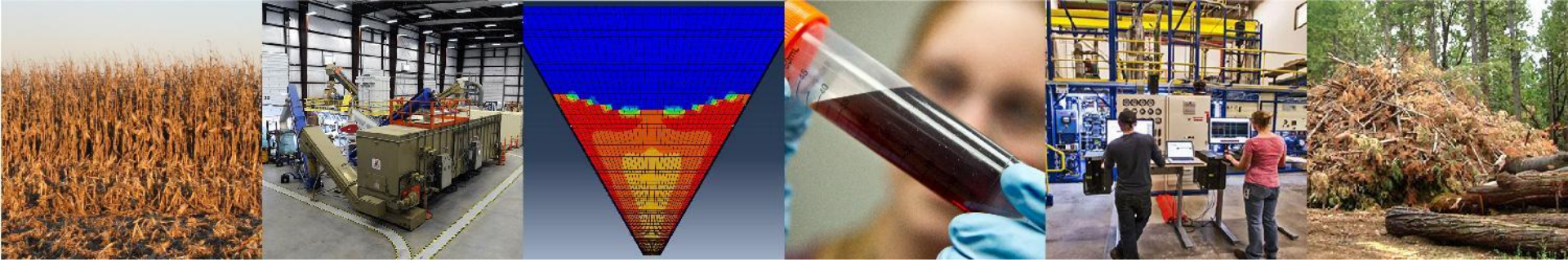
- Collect representative corn stover and pine residues for the 3 year project
- Quantify range and frequency variability
- Identify origins of variability
- Document information

Data Acquisition and Analysis

- Harmonization of methods & vocabulary
- Collect existing analytical data for variability ranges/identify gaps
- Track the history and quality of representative FCIC biomass samples
- Machine learning component to identify correlations







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Tyler Westover, Hai Huang, Yidong Xia (INL)
Jonathan Stickel, Hariswaran Sitaraman (NREL)
George Fenske, Oyelayo Ajayi (ANL)
Carl Wassgren (Purdue University)
Bryan Ennis (E&G Associates)
Kerry Johanson (Material Flow Solutions)

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Feedstock performance modeling

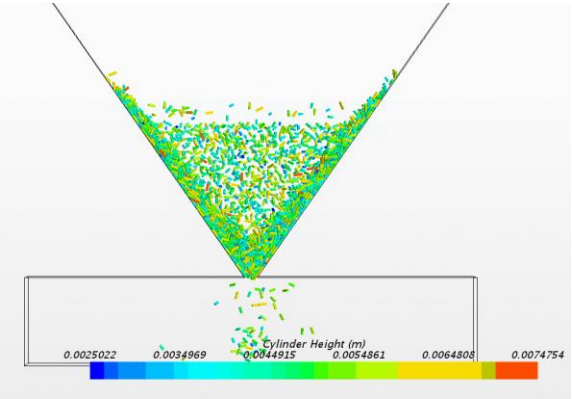
History:

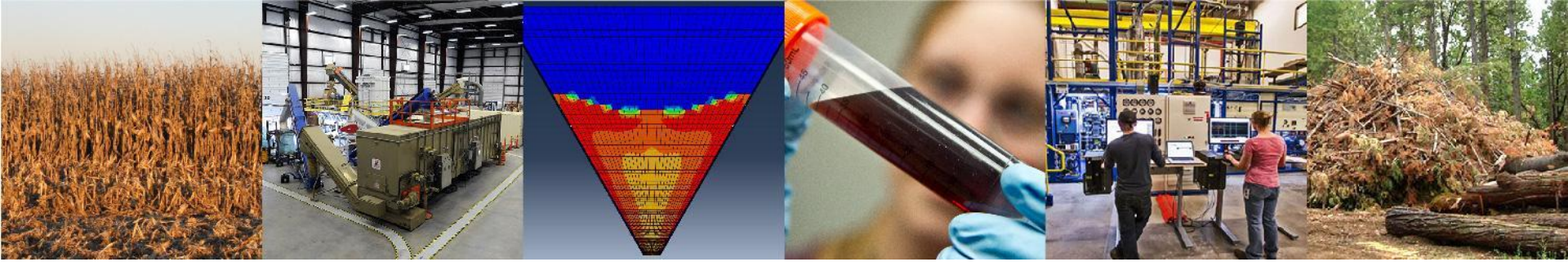
- Lack of real biomass behavior models

Objective: Use mechanistic modeling to identify the causes of feed-handling failures and validate model driven design changes to lead to improved process and equipment performance

Technical Approach

- Particle models (discrete element method, DEM)
- Reduced-order continuum models (averages over many particles)





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Ed Wolfrum, Melvin Tucker, Erik Kuhn, Xiaowen Chen, Dan Carpenter, Kristin Smith, Bryon Donohoe, Nick Nagle, Peter Ciesielski (NREL)

Vicki Thompson, John Aston, Tyler Westover (INL)

Jim Kieser, Jim Parks (ORNL)

George Fenske (ANL)

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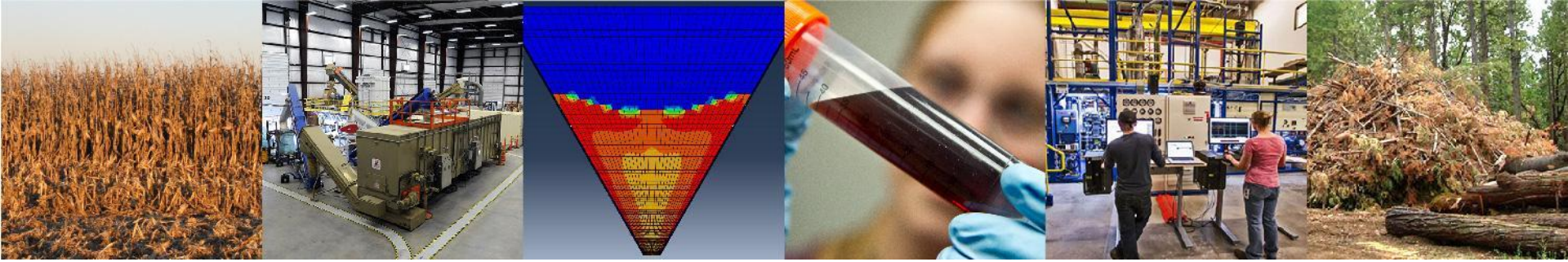
Process Integration

History:

- Lack of feedstock variability effects on operational Reliability information
- PDUs have chased yield

Goals:

- **Execute robust, industrially-relevant baseline testing** both low- and high-temperature conversion processes
- **Longer-Term Goal is to develop and demonstrate cost-effective mitigation strategies**
- Support other FCIC projects through experimental **validation**



Biomass Quality

- Feedstock Variability and Specification Development — *Allison Ray (INL)*
- Feedstock Physical Performance Modeling — *Tyler Westover (INL)*

Upstream-Downstream Process Integration

- Process Integration — *Ed Wolfrum (NREL)*

System Readiness Evaluation

- **System-wide Throughput Analysis** — *Dave Thompson (INL)*
- Process Control and Optimization — *Quang Nguyen (INL)*

Characterizing Biomass & Mining Data

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David N. Thompson, Damon Hartley (INL)
Michael Wang, Hao Cai, P. Thatiana Benavides (ANL)
Mary Biddy, Ryan Davis, Abhijit Dutta (NREL)
Erin Webb (ORNL)
Steve Phillips (PNNL)

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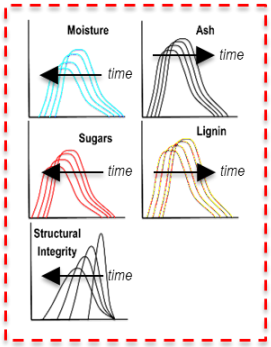
System-wide reliability modeling

Objectives

- Captures system-wide feedstock variability impacts to throughput and yield
- Model the operational reliability of one low-temperature (LT) and one high-temperature (HT)

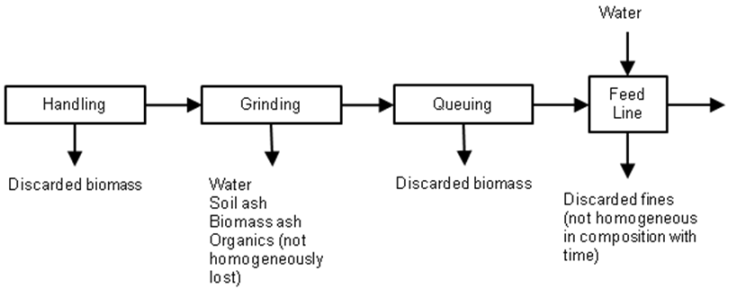
Approach

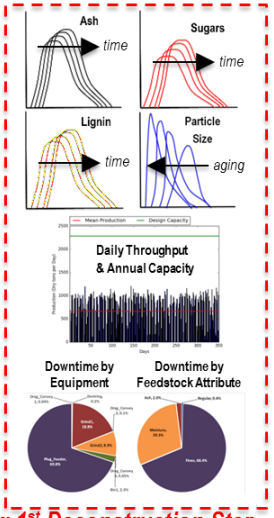
- Dynamically model from the field to the biofuel
  - Develop discrete event throughput analysis approaches leveraging those developed at ORNL and INL for modeling biomass supply chains
  - Utilize existing steady state conversion process models, modified to allow mass and energy balance assumptions to be adjusted
  - Develop an integration framework to allow the entire system from harvest through biofuel to be analyzed quickly and efficiently



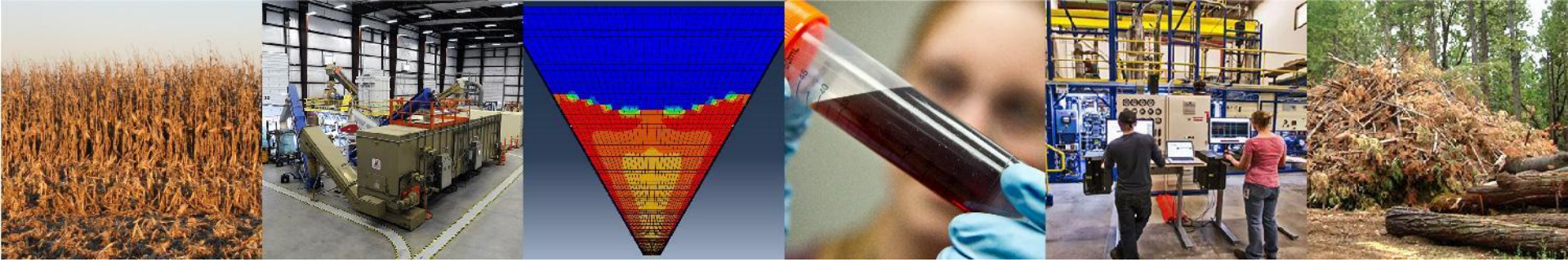
Biorefinery Gate

Conventional preprocessing with design assumption of 350 days/year uptime





Entering 1st Deconstruction Step



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INL: Quang Nguyen, Matthew Anderson, Robert Kinoshita, William Smith, Patrick Bonebright, and Neal Yancey

NREL: Richard Elander, Kristin Smith, Danny Carpenter, David Sievers, Katie Gaston, and Raymond Hasen

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Project Objective

History:

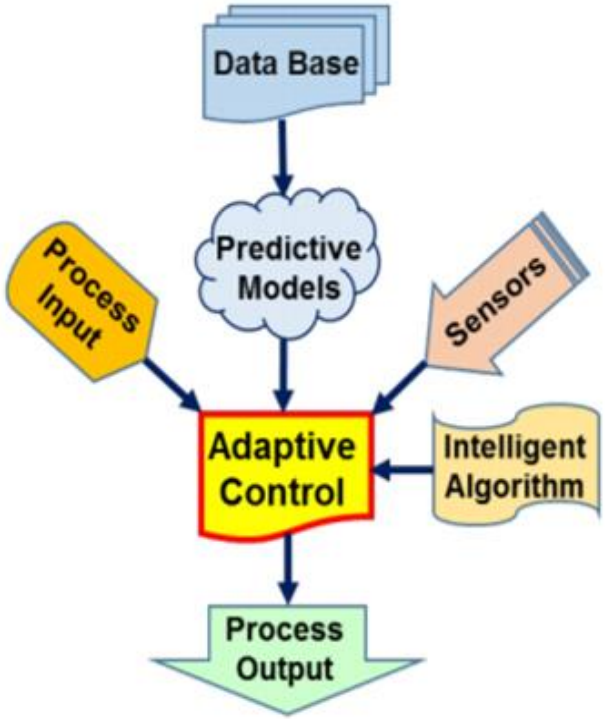
- IBRs are run with human interventions

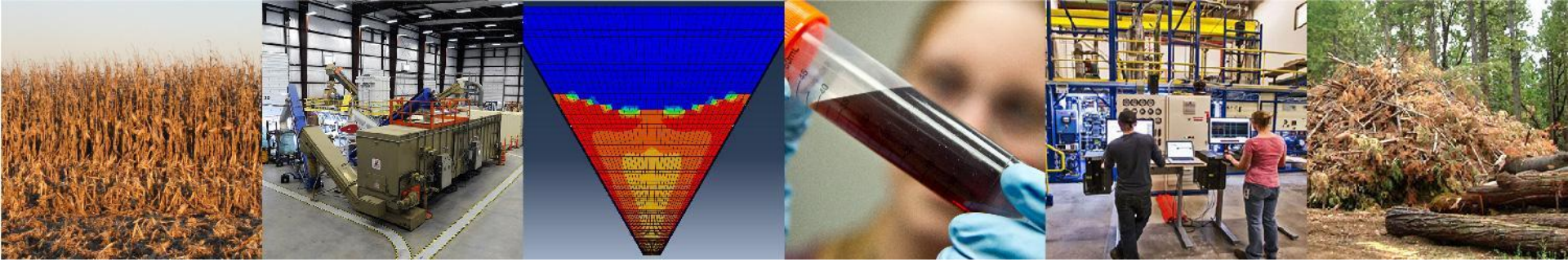
Goal:

- Verification and design control systems that increase the on stream **reliability** in industrially relevant conditions while **maintaining primary deconstruction conversion performance.**

Objectives:

- Test dynamic control systems that can adapt in real time to changing biomass composition and process conditions





Questions?

Michael.resch@nrel.gov

BIOECONOMY

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