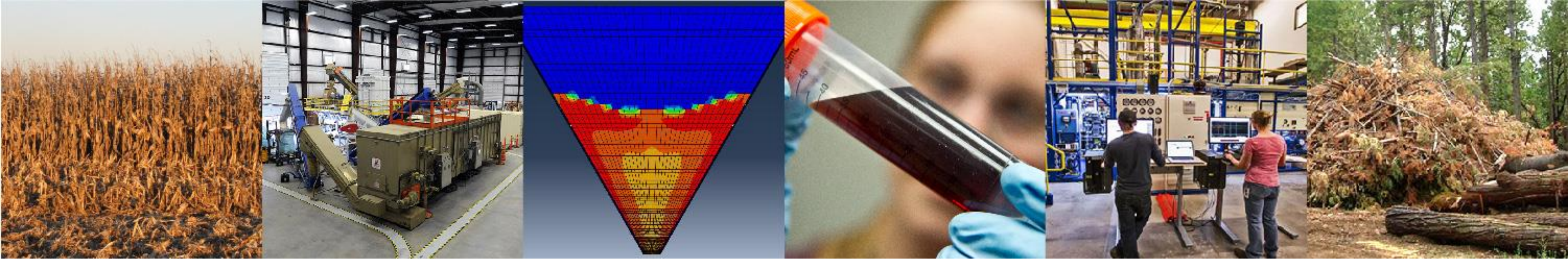

Process Control and Optimization

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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FCIC Kick-Off Meeting; Golden, CO

fcic
FEEDSTOCK-CONVERSION INTERFACE CONSORTIUM

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Project goal (end of 3 years)

Verification of an artificial intelligence based control system (and underlying predictive and intelligence models) that results in **>90% reliability** and **> 50% capability** (relative to design capacity) in industrially relevant conditions for preprocessing through 1st-stage low-temperature & high-temperature deconstruction while **maintaining primary deconstruction conversion performance.**

Project Objectives

- To develop and **optimize process control systems** to improve the operating reliability of the preprocessing and 1st-stage deconstruction reactor systems for low-temperature (corn stover) and high-temperature (loblolly pine residue) conversion pathways.
- To determine the **dynamic relationship between key process parameters** to establish appropriate equipment and process design criteria to enable reliable operations and maximize throughput.

Approach to Improving Operating Reliability & Throughput

Inputs → Preprocessing & Primary Deconstruction → Outcome

Inputs

- Corn Stover
- Loblolly pine residue
- **Variable properties**

Preprocessing & Primary Deconstruction

- **Equipment performance characteristics**
- **Physical/Process Models** predicting equipment performance
- Matching equipment capacity in an integrated system
- **In-line sensors** for measuring biomass properties (e.g., moisture, ash, “brittleness”, particle size, composition)
- **Intelligent, adaptive control** for integrated system

Outcome

- **Consistent feedstock quality**
- **High conversion yield**
- **Improved operating reliability**
- **High throughput**
- **Transfer of technologies to industry**

Tasks

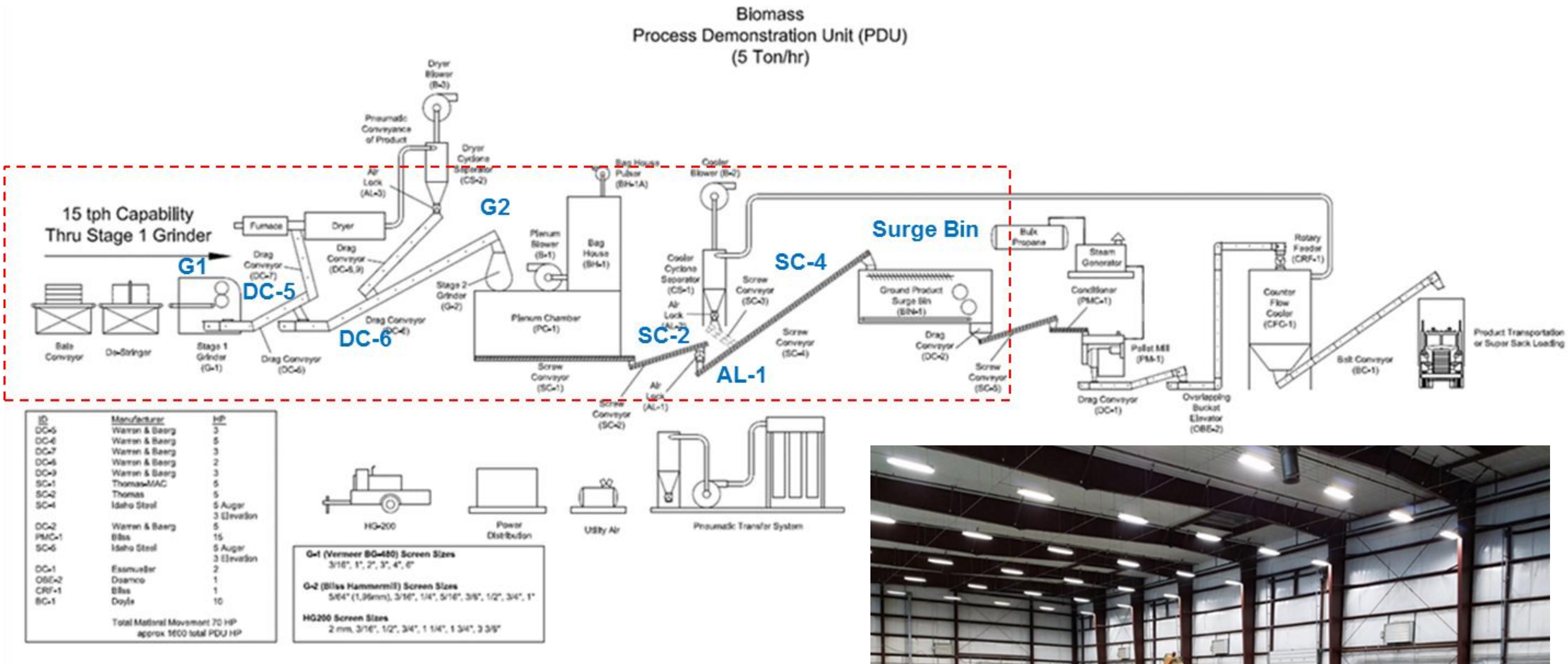
Task	Lead Lab	PI
Task 1. Process Control and Optimization 1.1 Intelligent Adaptive Control System 1.2 In-line instrument & sensors for intermediate streams 1.3 Equipment performance characterization & design criteria	INL	Quang Nguyen
Task 2. In-line Moisture Measurement of Biomass Feed Materials using Low-frequency Microwave Sensor	INL	Bill Smith

NREL Plug Screw Feeder

Gazeeka Bale Moisture Sensor

In-line NIR Probe (on DC-5) measures moisture, ash, glucan & xylan content of milled corn stover

Background: Adaptive Control System Development

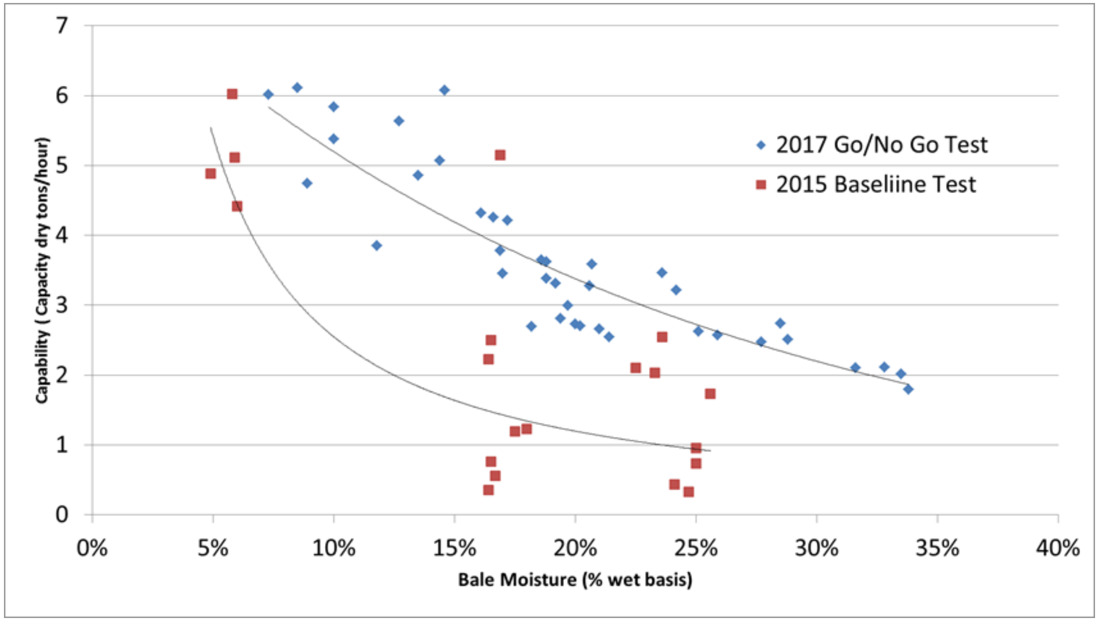


BFNUF Two-stage Grinding of Biomass

Adaptive control system improves the operating reliability of feedstock preprocessing

fcic FEEDSTOCK-CONVERSION INTERFACE CONSORTIUM

- A 20-ton Go/No-go run in FY 17 Q2: Human-in-the-loop adaptive control system improved the **operating reliability** (on-stream time) of a **2-stage grinding** operation from 63% to **96%** for **high-moisture** corn stover bales.
- The FCIC will **incorporate 1st-stage deconstruction** coupled with in-line monitoring to enable **reliable** and **controlled operations**



Effects of Feedstocks Properties on Preprocessing

- **Examples from gap analysis exercise**

Biomass Property	Potential Impact on Throughput & Feedstock Quality
Moisture content of biomass	**High: Low throughput** in grinders, conveyors, and screens; larger particle size, less fines **Low: Higher fines** fraction and **dry matter loss**
Ash content of biomass	High ash and dirt content causes accelerated wear on equipment which leads to **frequent downtime**, **plugging** and **low throughput** on grinders and screw conveyors
Age/storage conditions	Microbial degraded biomass has low fiber integrity which causes **low throughput**, **plugging** of equipment, high amount of **fines**, high **dry matter loss** in preprocessing, and **carbohydrate losses**
Baled biomass	Random orientation of biomass materials causes **wide particle size distribution**

Effects of Feedstocks Properties on Conversion – Low Temperature

- **Examples from gap analysis exercise**

Feedstock Property	Potential Conversion Effect
Moisture content of biomass	**High**: Pretreatment reactor/plug **screw feeder flooding**, low solids loading effects on residence time, **pretreatment yields**, sugar/ethanol concentrations, **throughput** (vessel volume limitation) **Low: Overuse of pretreatment chemicals** (yield), high solids loading in enzymatic hydrolysis reduces overall conversion yields
Ash content of biomass	**High: Additional chemicals** (pretreatment/neutralization) – effects **sugar yields** and **fermentation performance** **Low:** Overload of pretreatment chemicals – increased pretreatment severity, **sugar yield loss**, **inhibitors** in fermentation
Particle size distribution	**Large:** plug formation, high fill factor (residence time), uneven chemical impregnation (yield), **incomplete enzymatic hydrolysis** (yield) **Small:** fines plugging and **losses through weep holes** (throughput), over-pretreatment – sugar yields and fermentation **inhibitors**
Composition (carbs/lignin)	High lignin and low carbohydrate content: Recalcitrance – **lower yields** OR higher pretreatment severity (chemicals use, sugar yields, inhibitors)
Age/storage conditions	Microbial growth: **Carbohydrate loss** and increase in relative lignin content (yield, throughput), change in feedstock flow properties and residence time distribution (**yield**)

Effects of Feedstocks Properties on Conversion – High Temperature

- **Examples from gap analysis exercise**

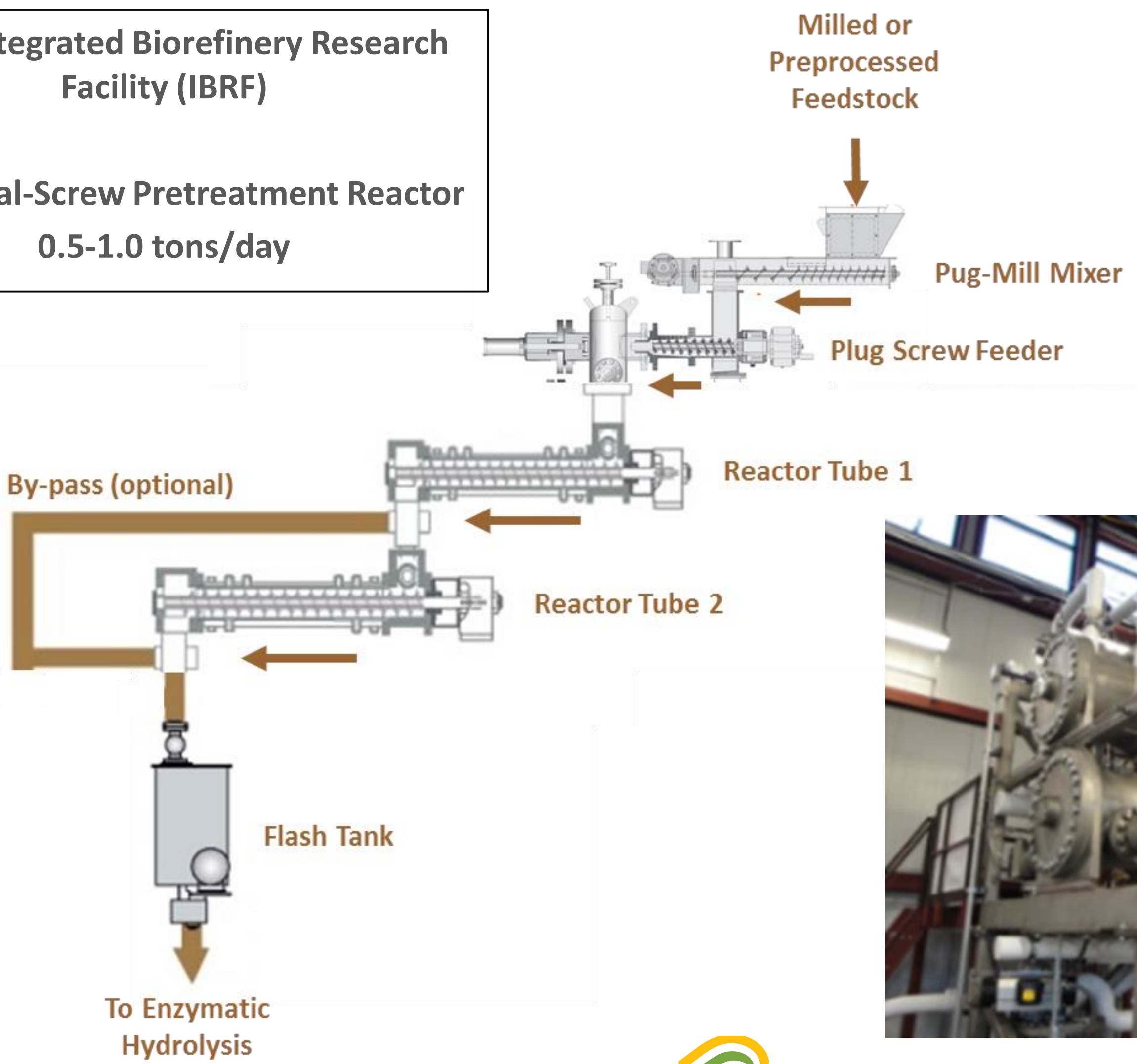
Feedstock Property	Potential Conversion Effect
Moisture content of biomass	High moisture causes increased intra-particle cohesion, resulting in clumping and bridging in feed hopper and feed screw; disrupts reactor heat balance/requirements; slows heat transfer into particles, resulting in **incomplete conversion**; causes increased water content in oil intermediate, potential **liquid phase separation**
Ash content of biomass	High ash increases solids handling and **disposal requirements**, potential for **carryover into catalyst or scrubber**
Ash composition of biomass	Alkali, alkaline earth, and transition metals catalyze char, gas, and water forming reactions, lowering organic product yield and changing composition; sulfur and chlorine increase corrosion in process and catalyst poisoning; alkali metals released (as vapor or aerosol) can form **deposits and poison downstream catalysts**; ash fusion (e.g. char combustor) causes **bed agglomeration**
Particle size distribution	**Low**: Excessive fines can cause **compaction in feed screw** and **losses** in feed train; carryover into scrubber/**blockage** **High**: Oversize particles cause physical blockage in feeder or conversion process; **incomplete conversion** to intermediates; **changes product distribution**, composition of intermediates

Low-Temperature Primary Deconstruction

NREL Integrated Biorefinery Research Facility (IBRF)

Horizontal-Screw Pretreatment Reactor

0.5-1.0 tons/day

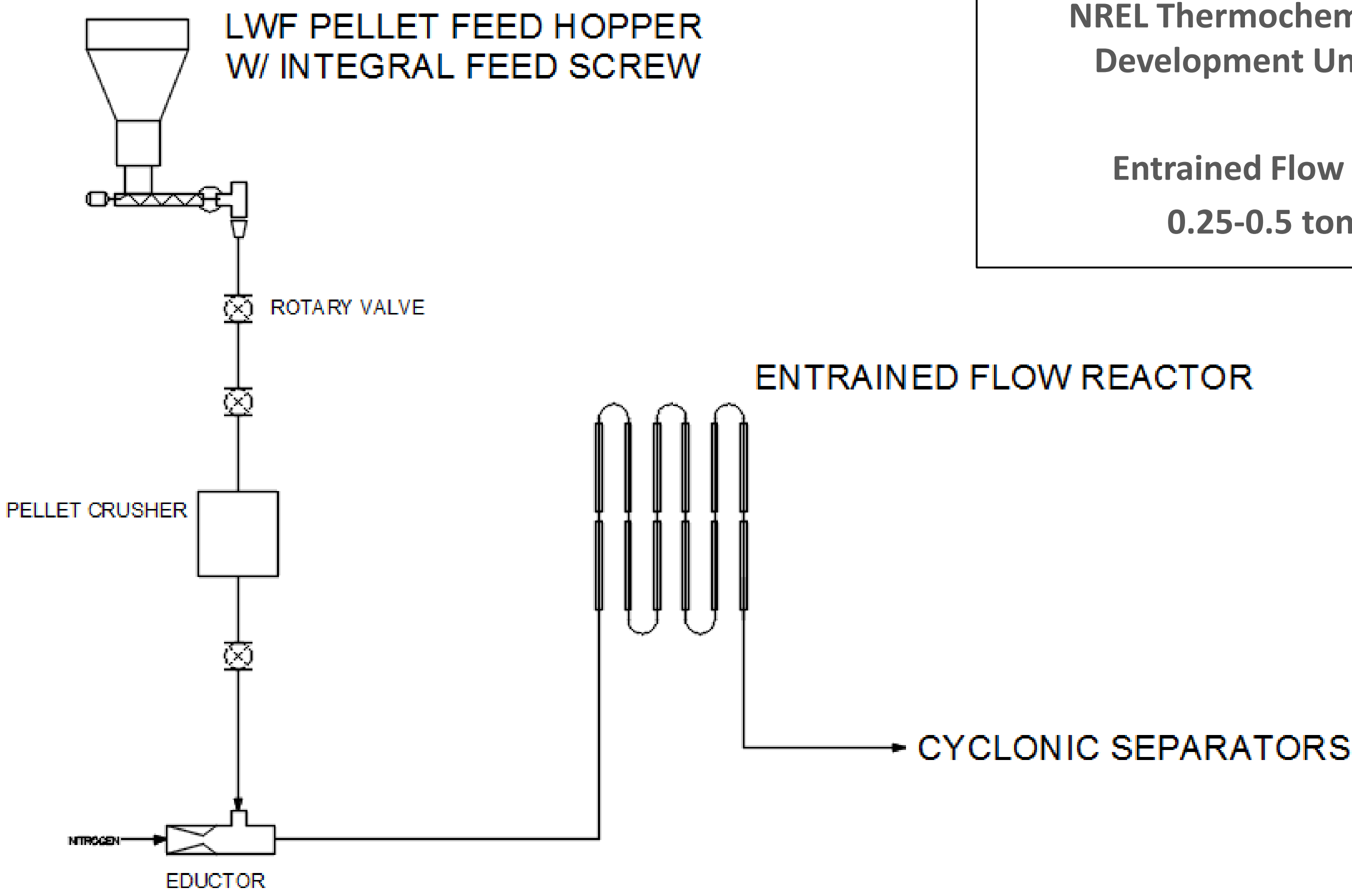


High-Temperature Primary Deconstruction

NREL Thermochemical Process Development Unit (TCPDU)

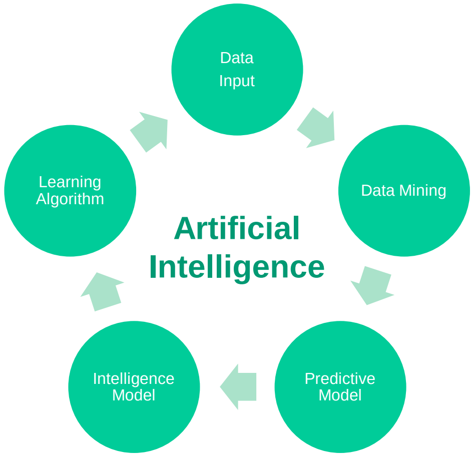
Entrained Flow Pyrolyzer

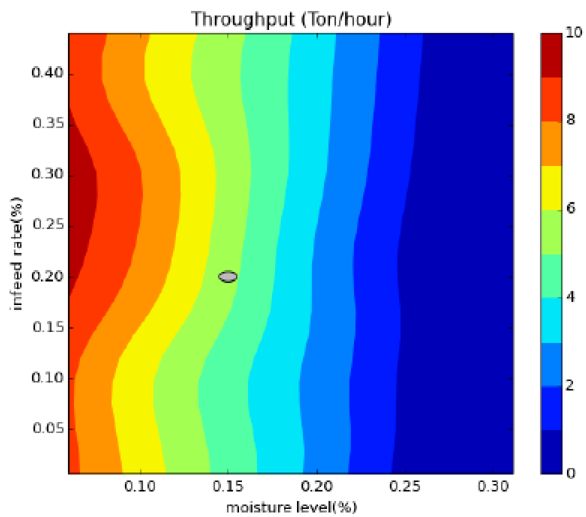
0.25-0.5 tons/day



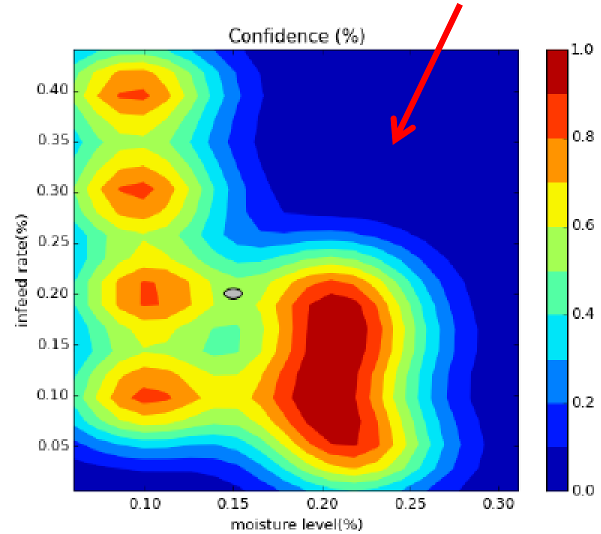
Intelligent Adaptive Control System

- Data input and mining, and developing predictive models
- Develop intelligence models
- Develop learning algorithms
- Automatically add the learned data to the database
- Repeat the cycle – this is the artificial intelligence approach as opposed to a physical/process model approach





Low confidence due to
- Data gaps
- Poor correlation



Predictive model of hammer mill throughput

Process Control and Optimization

- National Lab Process Development Units (PDUs) generate a wealth of pilot **data** which **can be mined** to develop **Adaptive Control Systems** for those Unit Operations
- However, **IBRs**, having different integration of unit operations, will **require run time** to collect sufficient data **for developing reliable adaptive control systems**.
- For **designing/operating new IBRs**, **Physical/Process Models** are useful to:
  - Manufacturers to **design** and **establish equipment performance characteristics** that reliably process biomass with varying properties
  - Technology developers and EPC companies to **select appropriate equipment** and develop process integration that provide robust operation
  - IBR operators to **develop control logics** for equipment to **obtain stable operation** and produce feedstock that **meet specifications**

Equipment Performance Characterization

Major feedstock handling equipment in a biorefinery:

- **Size reduction**: bale breaker, shredder, hammer mill
- **Contamination removal**
  - Air density separator (stand alone, integrated with conveying system)
  - Screens (trommel, vibrating)
- **Conveying**
  - Mechanical conveyors: helical, paddle, drag chain, belt, shaftless
  - Pneumatic conveyors: dense phase, dilute phase, pressure, vacuum
- **Storage bin**

Major conversion (primary deconstruction) equipment – Low T example:

- **Catalyst addition system:** in-line mixer, dewatering press
- **Pretreatment Reactor feeding system**: metering bin, plug screw feeder
- **Pretreatment Reactor**: solids and chemical loading, residence time
- **Pretreatment Reactor discharge system**

Performance Characteristics of a Hammer Mill – Pre-processing Example

Input/Variables	Impact
Feed rate	Throughput, particle size
Moisture content of biomass	Higher breaking force, higher energy consumption
Weak fiber integrity (e.g., brittleness)	Lower breaking force
Windage (vacuum pulled on outlet)	Throughput, particle size, fines
Bulk density of feed	Throughput, particle size
Impact force (tip speed, knife design)	Throughput, particle size, fines
Screen size and design	Throughput, particle size
Knife position (distance from screen, variable length of knives)	Throughput, particle size, fines
Spacing between knives	Throughput, particle size, fines
Orientation of corn stalks	Significant reduction of energy required cutting along the length (but “bird nest” is produced)

Performance Characteristics of a Plug Screw Feeder – Conversion Example

Input/Variables	Impact
Particle size, bulk density & fill factor	Plug formation, throughput
Fines content	Loss of materials through weep holes
Rotational speed	Throughput, wear on feeder
Moisture content of biomass	Plug formation, throughput
Ash content of biomass	Wear on feeder
Plug pipe configuration	Throughput, plug formation
Reactor pressure and temperature	Plug formation, wear on feeder
Design of weep holes and spray bars	Throughput

Links to other FCIC Projects

Project	From Process Control and Optimization	To Process Control and Optimization
Feedstock Variability and Specification Development	**Feedstock samples** prepared under various conditions	**Physical properties**: bulk density, PSD, compressibility, moisture, ash content
Feedstock Physical Performance Model	**Feedstock samples** prepared under various conditions. **Equipment performance data**	**Physical/process models** to guide equipment design, set-up and operation
System-wide Throughput Analysis	**Equipment performance data**, effect of controls strategy on modeled reliability and performance	**Gap analysis**, **TEA modeling impacts** of feedstock properties on conversion performance
Process Integration	**Equipment performance data**, implementation of controls on preprocessing and conversion equipment	**Baseline and mitigation equipment performance data** will inform controls needs

Questions?