#### **Biomass Feed Handling** The Case for Science and Technology Innovation

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With input from TA Bell, Challenges in the scale-up of industrial processes – an industrial perspective. Powder Technol. 150 (2), 60-71(2005).

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#### User Facility Feed Processing & Handling Experience

- Fully integrated pilot plant with commercial scale processing equipment
- Modular design allows the insertion of third-party equipment
- Extensive material characterization and data collection
- More than 1,000 tons of feedstock processed to a wide variety of conversion pathway specs
- Offering
  - Toll processing/piloting
  - Toll characterization
  - 3<sup>rd</sup> party testing & validation
  - Process development
  - Preprocessing R&D



PDU is located in 27,000-ft<sup>3</sup> high bay at INL's Energy Systems Laboratory

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#### **The Feed Handling Problem**

- Rand Corporation study from 1980's showed that plants that process bulk solids typically operate at less than 50% of design capacity the first year of operation
- DOE sponsored study followed significant difficulties in the start-up of new synthetic fuel plants
- Performance of 37 new plants using data provided by 25 companies
- Problems generally relate to an inadequate understanding of the behavior of particle systems (Bell 2005)



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#### **The Feed Handling Problem**

- That was a long time ago, hasn't this improved?
- Look at the data…
  - Through Nov 2015, 2.0 million RINS generated from cellulosic ethanol; estimate ~3% of production capacity
- Inadequate understanding of the behavior of particle systems
- Feedstock variability and the limitations of current systems to handle it is a significant factor





### **Industry Feed Handling Problems**

- Moisture
  - Grinder throughput
  - Particle size variability
  - Variation causes inconsistent mass and heat transfer in conversion
- Particle Size
  - Large particles (aka pin chips)
    - Cause plugging problems in bins, augers
    - Do not fully cook plugging in downstream equipment, microbial contamination
  - Fine particles
    - High in ash
    - Dust fire, explosion, and health hazards
    - Plugging of weep holes in digesters
    - Buffering capacity, increase chemical usage
  - Variation causes inconsistent mass and heat transfer in conversion
- Foreign material (dirt, metal)
  - Plugging, equipment wear



#### Feed Handling Problem #1: Inconsistent Preprocessing Rate

- Plant with a required production rate of 1440 bales a day (1 bale/min)
- Feedstock supply has range of moisture content
- Preprocessing rate is a function of moisture content
- The grinder capacity function is based on PDU experience
- Bale moisture content of 20% yields 1440 bales/day through preprocessing
- Using a daily time step, with different moistures being brought to the facility each day
- Modelled a 60 day snapshot of the facility's bale processing rate





#### **Corn Stover Processing, Post Storage**



|                    | Random | Blended |
|--------------------|--------|---------|
| Average bales/day  | 897    | 897     |
| Stdev of bales/day | 871    | 198     |
| Low %              | 20%    | 32%     |
| High %             | 190%   | 100%    |

#### Feed Handling Problem #2: Flowability

- Root Cause: Variation in Flowability Moisture
- Solution: Active Controls to Not Overfeed



3/16" Grind Screen 30% Moisture Content 0.9 Dry Tons Hour Grinder Limited





1" Grind Screen 30% Moisture Content 1.6 Dry Tons Hour Conveyor Limited





#### **Plugging Screw Conveyor**

1" Grind Screen 11% Moisture Content 10.3 Dry Tons Hour Stage 2 Grinder Limited







#### **Plugging Screw Conveyor**



1" Grind Screen 30% Moisture Content 1.6 Dry Tons Hour Conveyor Limited







### **Plugging Screw Conveyor**







## Our Feedstock Paradigms May Be Indicative of the Problem

- Where is preprocessing?
  - If the feedstock supply chain ends at the plant gate and conversion starts at the reactor throat, where is preprocessing?
  - Does this mean it gets overlooked?
- What is preprocessing?
  - Just grinding
  - How hard can that be?





## Pilot Plant Testing is Recommended but Seldom Done

- Rand study makes a strong case for large scale, fully-integrated pilot plants using identical process components as the final plant
- Often the performance or each stage of the process is determined by the preceding one
- No one would ever scale-up a conversion process without piloting, so why is piloting feed processing not done?
- Three reasons for not piloting
  - 1. Ignorance of the issues and potential problems
  - 2. Pride engineers don't think they need to
  - 3. Haste to get product to market
- Failure to build and operate integrated pilot plants will cost time and money



#### **Duplication of Existing Plant is Common & Risky**

- Requirements for success are high
  - Identical feed materials and feedstock specs
    - Not only raw materials but also refined feedstock
  - Knowledge is shared freely among plants
  - Basic equipment in the process was optimally chosen initially
  - Products are consistent in quality and chemical nature
- Probability of success is low
  - Too many changes in the supplier/customer marketplace to exactly duplicate
  - Probable that the design of the first plant was not optimal to start with





Although processing steps are similar, systems for pulp & paper, pellet, and feed markets likely will not work for pioneer biofuels plants



#### **Too Much Reliance is Placed on Vendor Testing**

- Tests in vendor shops are better than no tests at all, but sometimes only slightly so
- Test equipment may be significantly smaller than the full size process
  - Even with a valid test, scale-up of vendor test data is often required
- It is extremely unlikely that the actual production material will match the test material
- Tests are too short to realize the nuances of feed variability and cumulative effects (e.g., wear)
- Few vendors can provide fully integrated processes in their test laboratory
  - Connections to upstream and downstream processes must be simulated
- Most (all) know their own equipment on an empirical basis
  - A vendor is likely to scale equipment for a new product based on prior experience with a different product
  - Lack the characterization facilities and technical skills to determine how old and new materials relate
- Pressure to make a sale forces them to be optimistic about capabilities of their equipment and own expertise



#### Why Particle Processes are so Difficult

- A particle system is more likely to be inconsistent than consistent
- Particles can almost be described as a fourth state of matter
  - They can develop cohesive strength and transfer stresses like a solid
  - They can retain air and take on fluid-like properties
  - They are often compressible and elastic like a gas
  - Unlike liquids and gases, particles often remember where they have been and never forget
  - Gases and liquids do not grow, agglomerate, aggregate or suffer attrition, particles do
- Materials process differently after being aged or subjected to repetitive handling
- Particle behavior often does not scale







#### The role of preprocessing is to produce a consistent feedstock





TC = Thermochem pathways BC = Biochem pathways

#### Feeding chopped & ground switchgrass in high tonnage equipment

| Material | Feed rate<br>(Dton/hr) | Duty<br>cycle (%) |
|----------|------------------------|-------------------|
| Chop     | 31.0                   | 0 (flood)         |
| Chop     | 29.8                   | 35                |
| Grind    | 4.9                    | 99                |

Womac, et al. Appl. Engin. Agric. 2015.



Westover, et al. Biofuels 2015 Across a range of particle sizes and shapes the only consistent difference was morphology of particle tips



Core Capability in Scale-up and Integration of Biomass Preprocessing allows Industry partners to take their Technology to Market





#### A Paradigm Shift Towards Innovation

- Plant gate and conversion throat are interfaces, not boundaries
- An effective feedstock supply chain is not just about yield or logistics, its about controlling uncertainty and variability
- The role of preprocessing is not grinding or drying or densifying. It is to produce a consistent feedstock
- An effective feedstock supply chain will be grounded in science and technology
- An integrated biorefinery understands its feedstock as well as it does its conversion process



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