Industrial Feed Handling of Lignocellulosic Feedstocks

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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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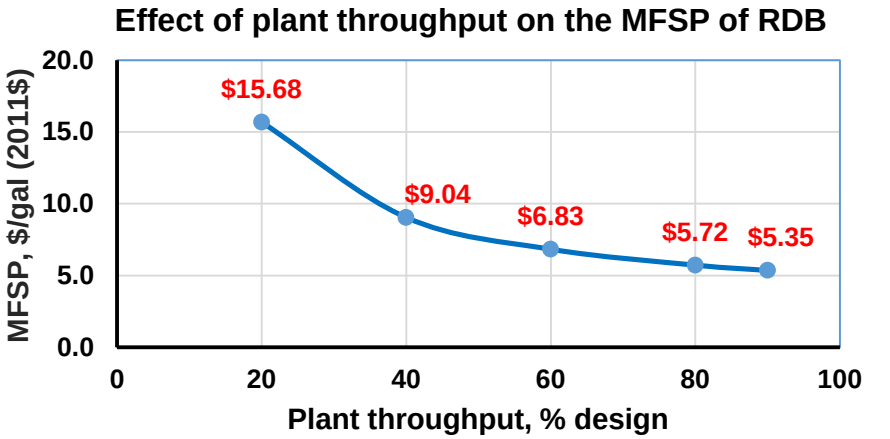
User Facility Feed Processing & Handling Experience

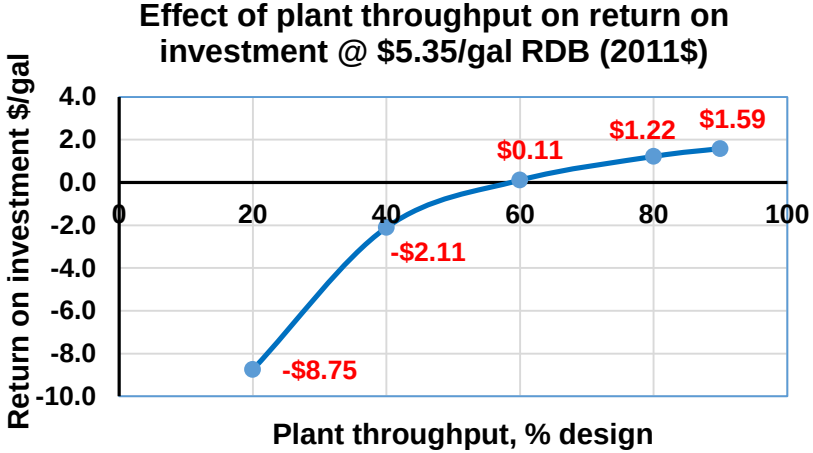
- Fully integrated pilot plant with commercial scale processing equipment
- Modular design allows the insertion of third-party equipment
- Extensive material characterization and data collection
- More than 1,000 tons of feedstock processed to a wide variety of conversion pathway specs
- Offering
  -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

Reconfigurable PDU is located in 27,000-ft³ high bay at INL's Energy Systems Laboratory

Observations from the emerging cellulosic ethanol market

- In 2015, 2.0 million RINS generated from cellulosic ethanol
- ~3% of biorefinery production capacity
- "Feed handling" problems blamed for slow start-up
  - Grinding
  - Conveyance
  - Feeding
  - Solids handling up to and through conversion





Biomass attributes related to 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

History repeats itself

- 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)

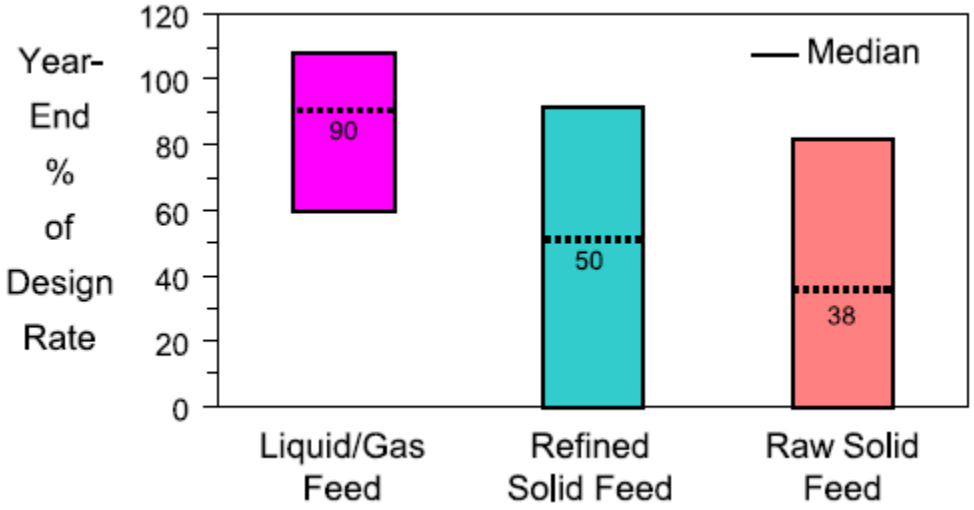
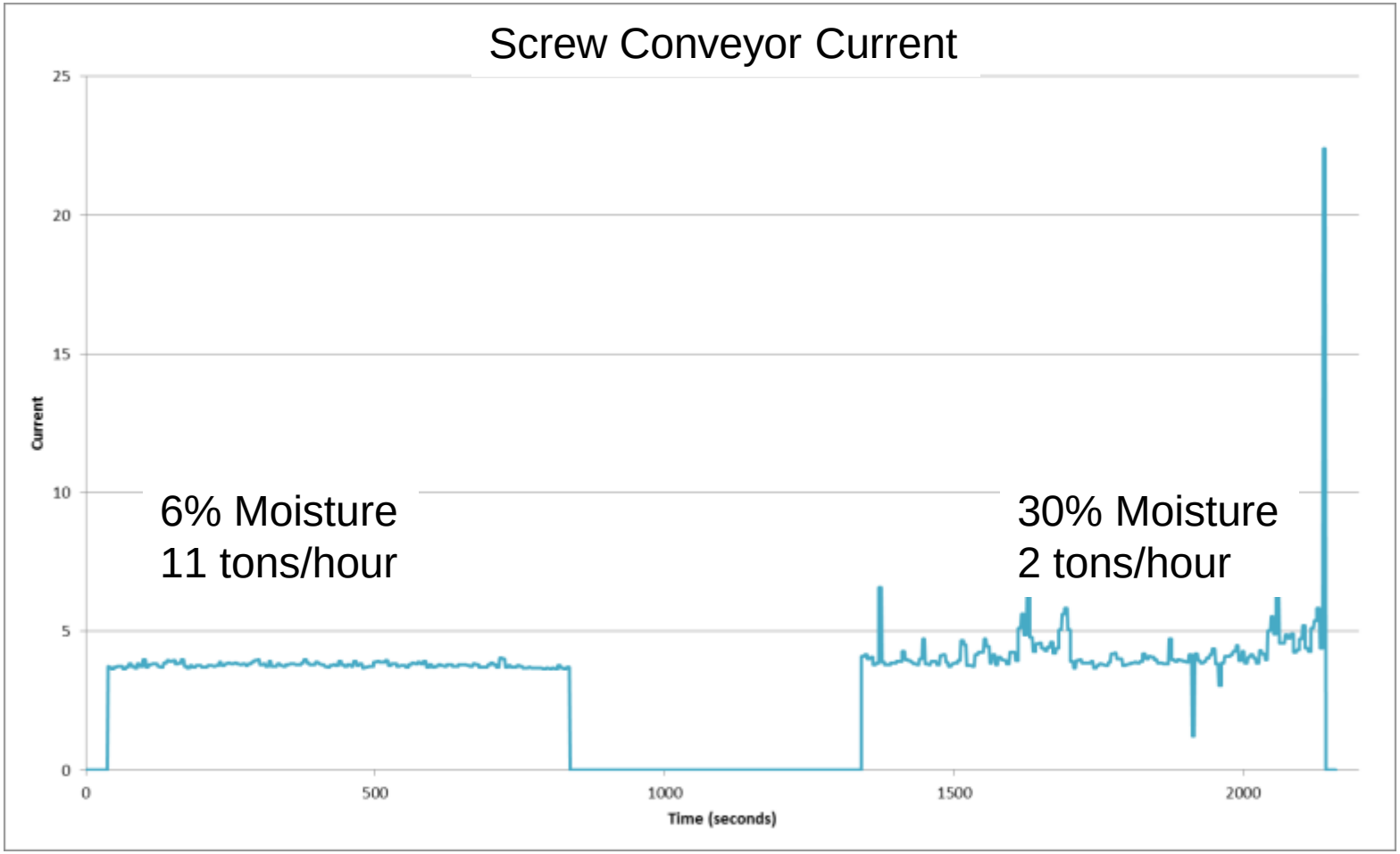


Image source: Merrow 1985

Why particle processes are so difficult

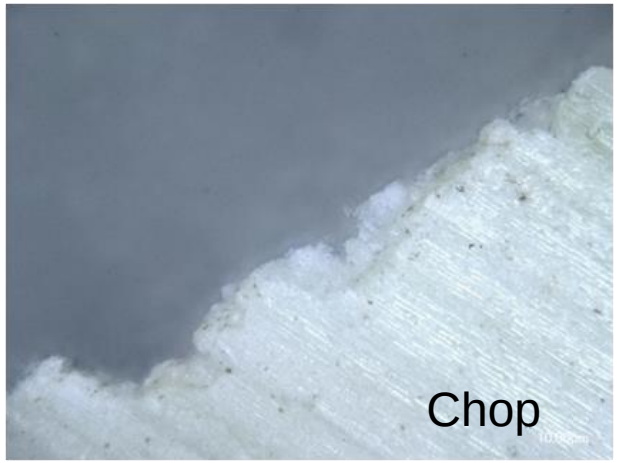
- A particle system is more likely to be inconsistent than consistent
- Particles can almost be described as a fourth state of matter
  - They can develop cohesive strength and transfer stresses like a solid
  - They can retain air and take on fluid-like properties
  - They are often compressible and elastic like a gas
  - Gases and liquids do not grow, agglomerate, aggregate or suffer attrition, particles do
- Material attributes can cause a transition from one state to another

Moisture effect on flowability



Particle morphology effect on flowability

Feeding ground & chopped switchgrass



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

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

Across a range of particle sizes and shapes the only consistent difference was morphology of particle tips

Westover, et al. Biofuels 2015

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 plants 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

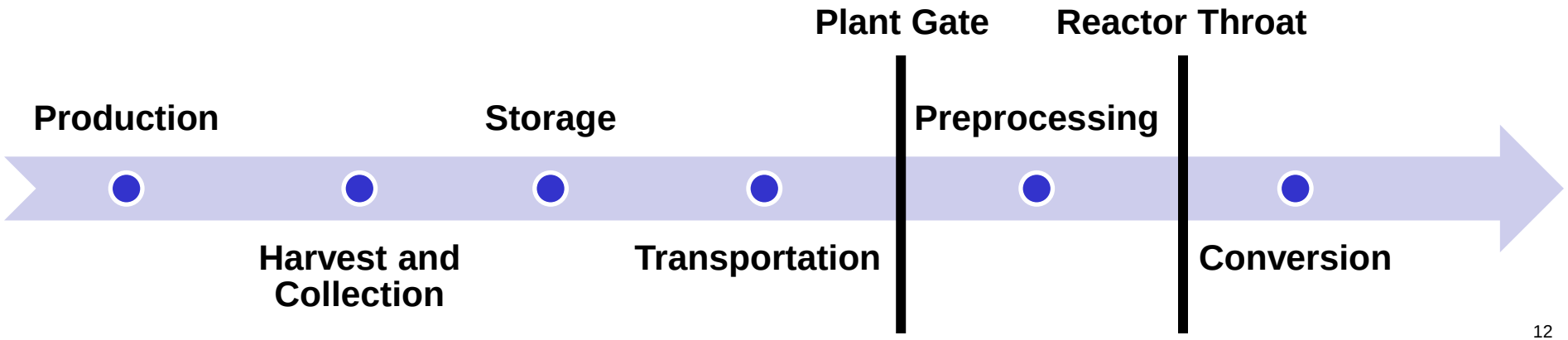
Although processing steps are similar, systems for pulp & paper, pellet, and feed markets likely will not work for pioneer biofuels plants

Too much reliance is placed on vendor testing

- Test equipment may be significantly smaller than the full size process
- 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
- 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
- Tests in vendor shops are better than no tests at all, but sometimes only slightly so

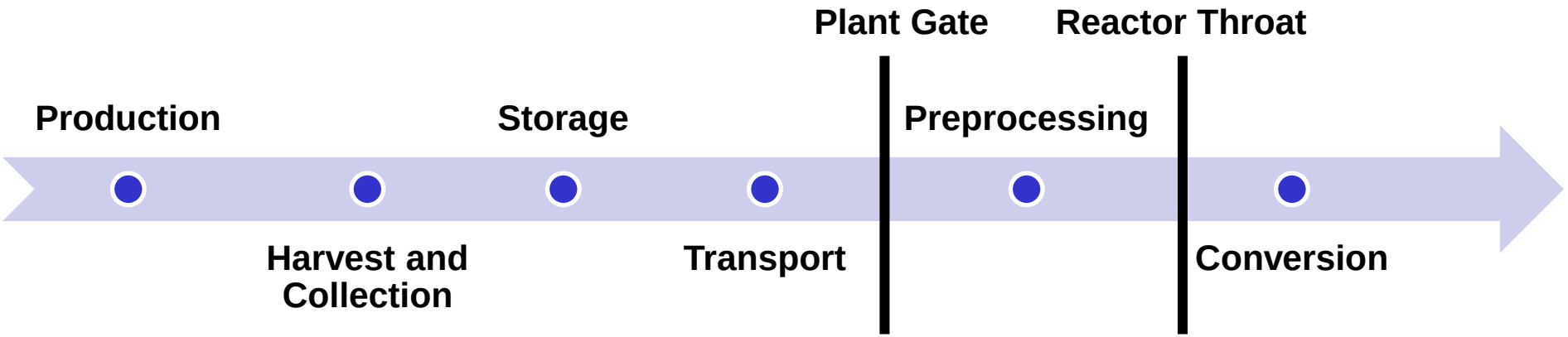
Our mindset about preprocessing may be indicative of the problem

- 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?
  - Preprocessing is seen as a cost, with little if any value
  - Just grinding
  - How hard can that be?



Preprocessing solutions to feed handling problems

- Biomass is difficult because it is compressible, elastic, and cohesive
- These properties vary among types and physical and chemical properties
- Feedstock variability and the limitations of current feed handling systems to handle it is a significant factor
- Consistency = Reliability = Lowest Cost
- The role of preprocessing is not grinding or drying or densifying. It is to produce a consistent feedstock



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