

Preprocessing and Pretreatment Technologies for Addressing Biomass Supply Chain Logistics

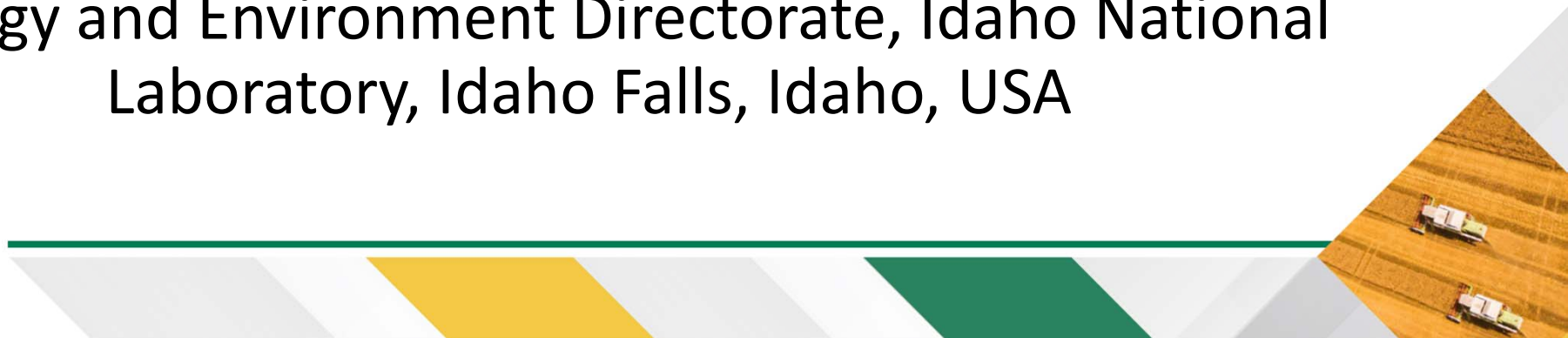
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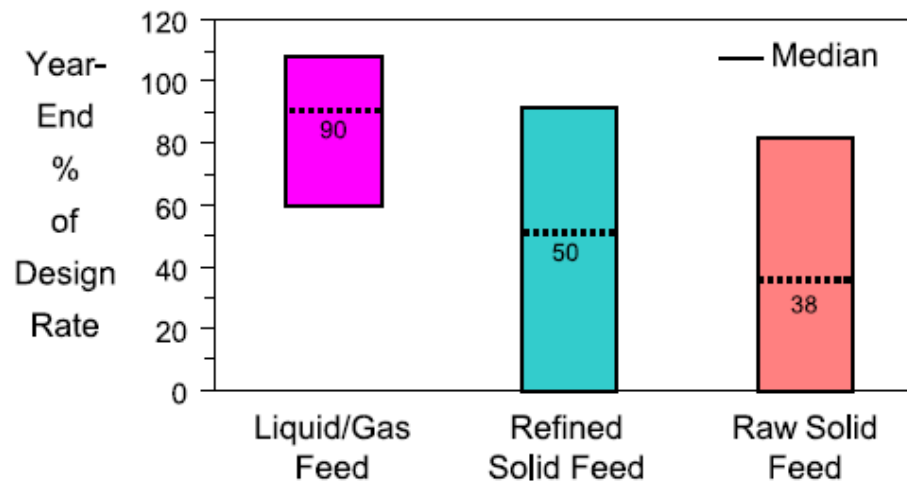
Observations from the Emerging Cellulosic Ethanol Market

- In 2016, 4.0 million RINS generated from cellulosic ethanol
- ~7% of the total active 57.75 million gallons per year (MGY) of nameplate capacity
- “Feed handling” problems blamed for slow start-up
 - Grinding
 - Conveyance
 - Feeding
 - Solids handling up to and through conversion



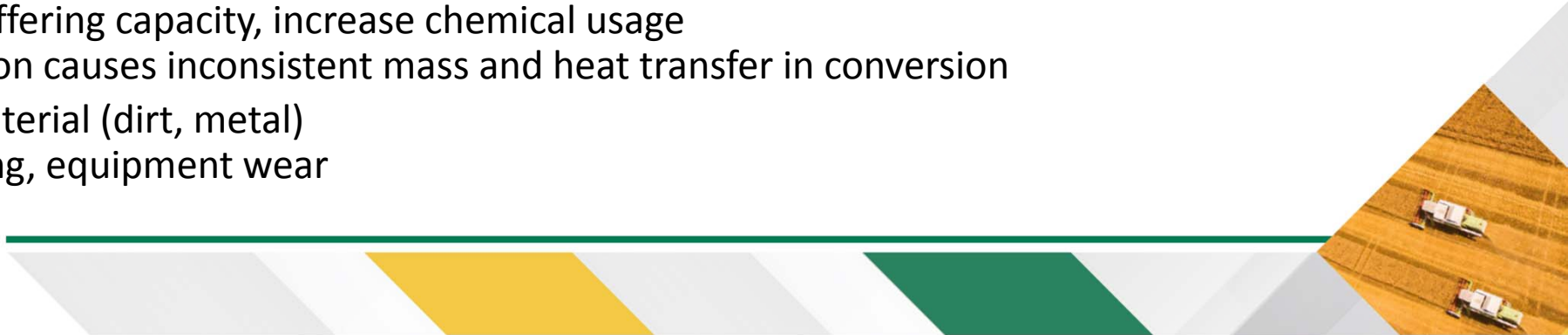
Industry lessons learned

- 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)



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



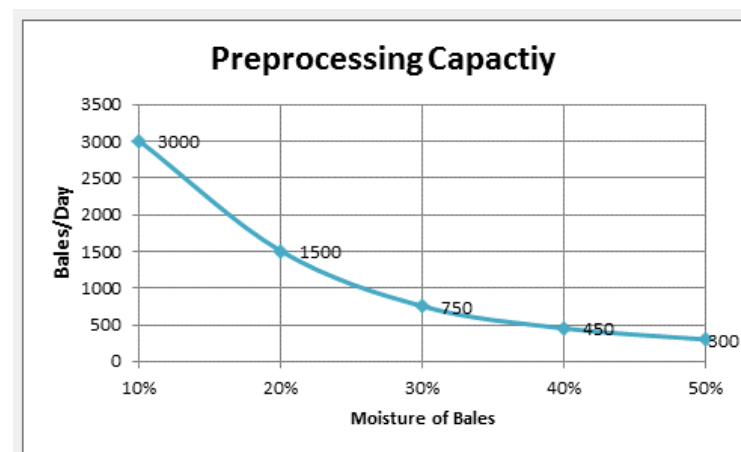
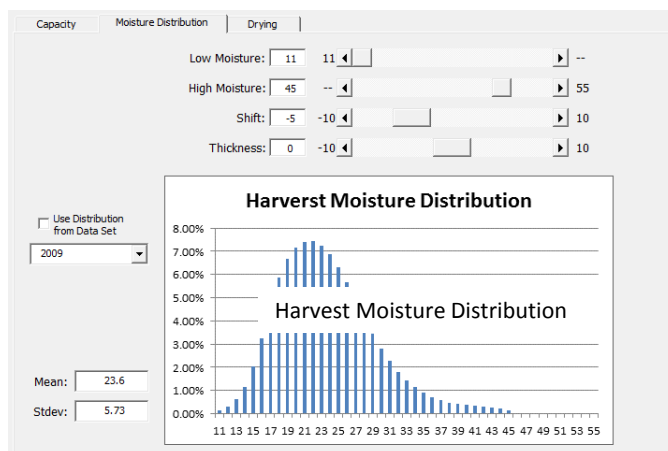
Why particle processes are so difficult

- 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



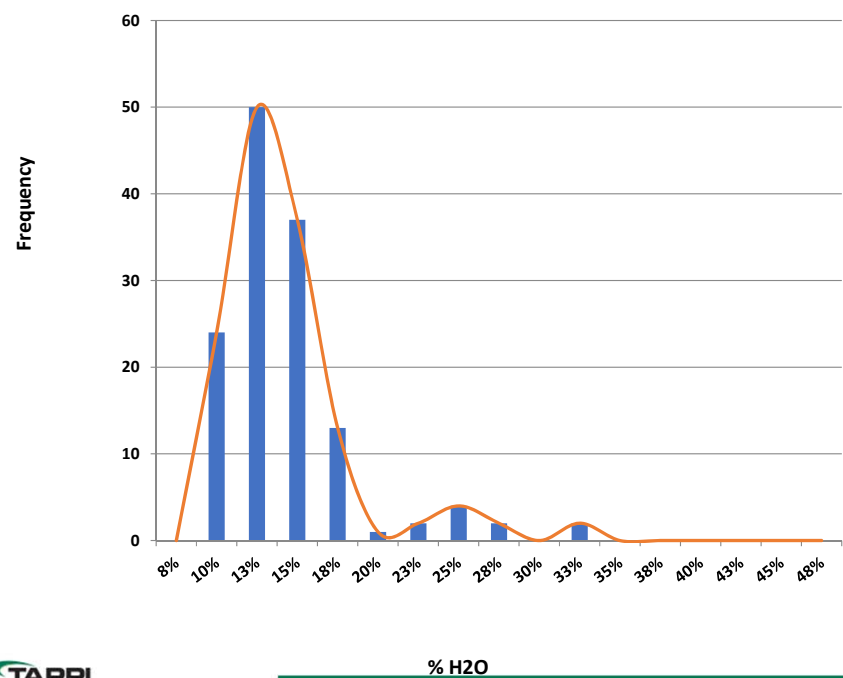
Example: Modeling Variability in Preprocessing Capacity

- 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

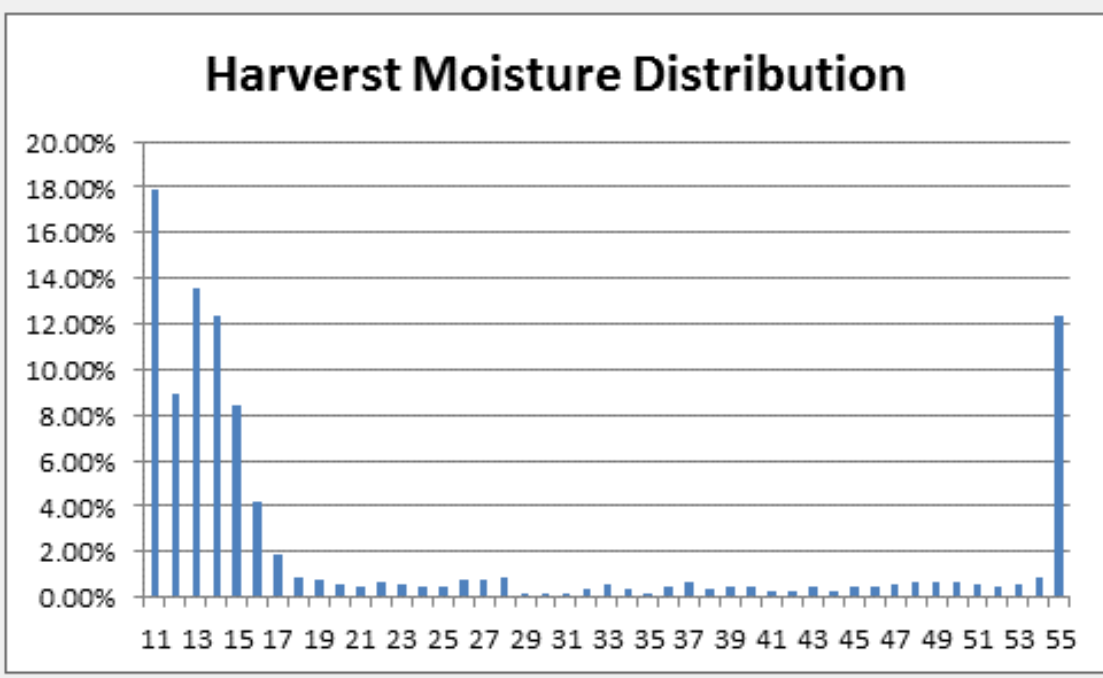


Moisture distribution data

As-Harvested
Bale Moisture (%)
Mean: 15.1
Stdev: 4.7

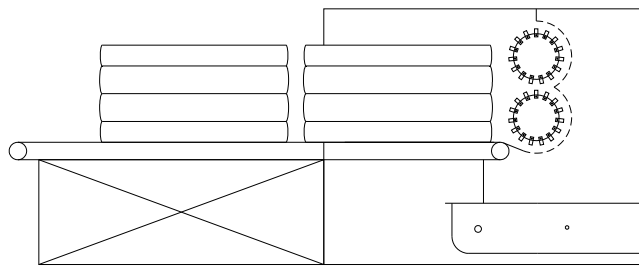


After 9 months of storage
Bale Moisture (%)
Mean: 22.8
Stdev: 16.0



Plugging Stage 1 Grinder Screens

- Root Cause: Variation in Moisture
- Solution: NONE in Extreme Cases, otherwise Slow!!



Horizontal Grinder Configuration



4" Screen



Bridging in Feedstock Bin

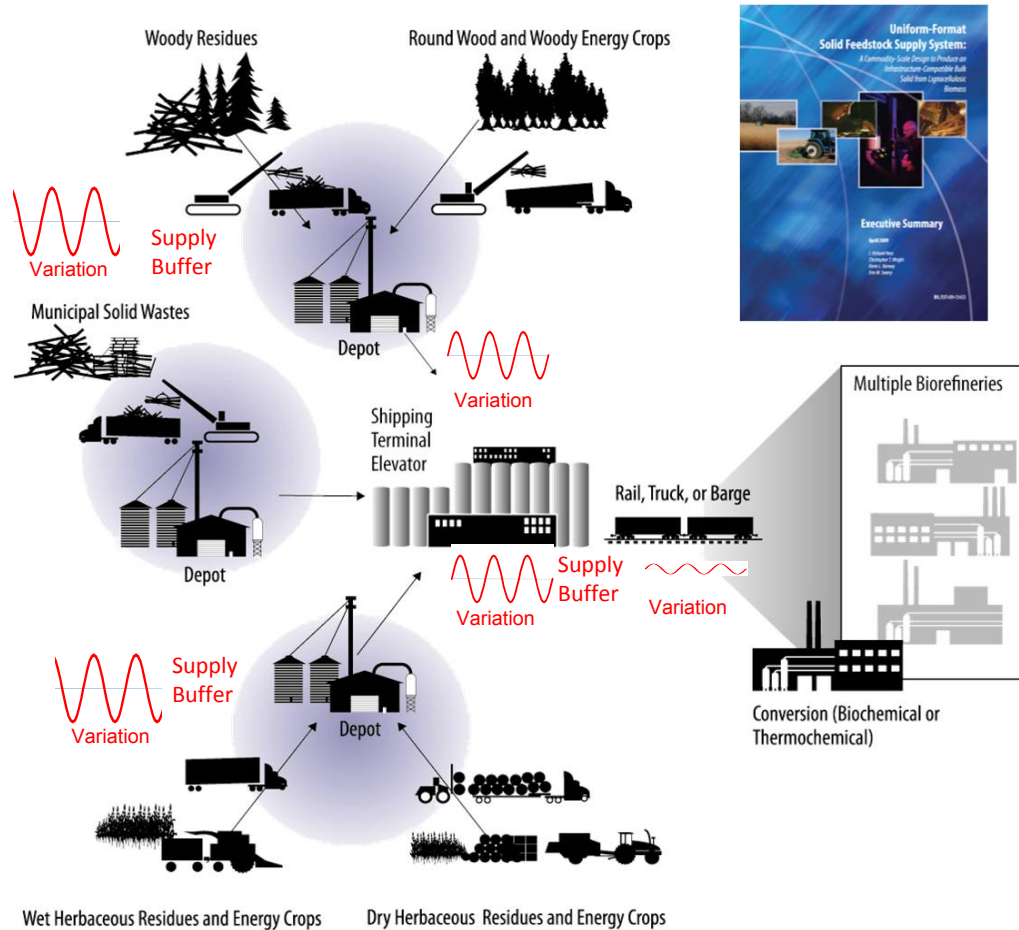


Commercial biorefineries have indicated difficulties in handling bales with variable moisture content.

Corn Stover Bridging in Drop Chute



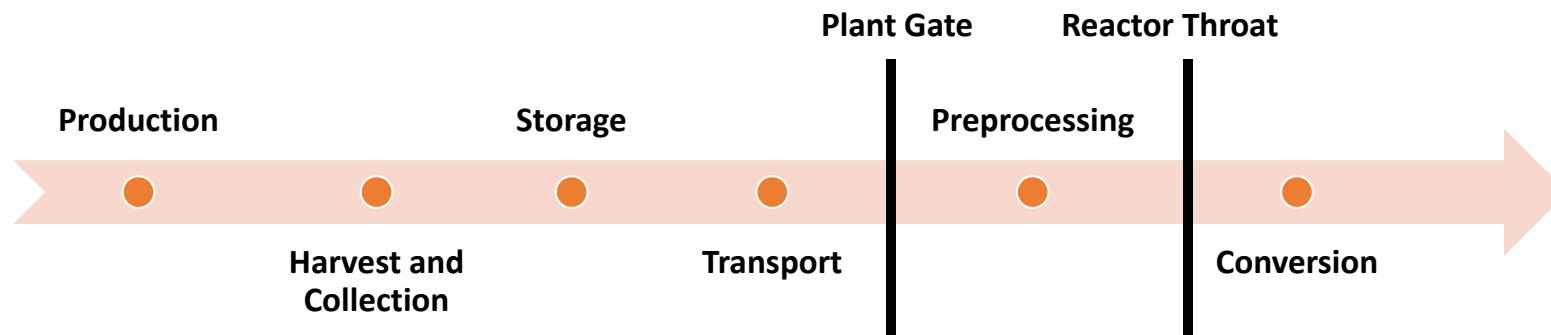
Decoupling Feed Processing from Conversion



- Wide-spread, interconnected supply network
- Stable, flowable, consistent, and conversion-ready feedstocks
- Reduced feedstock variability in quantity, quality, cost
- Decoupling does not eliminate the feed handling problem, but it does reduce conversion plant downtime.

Preprocessing

- Currently biorefineries are having challenges to operate at designed capacity due to variability of moisture and particle size.
- Biomass is difficult process because it is compressible, elastic, and cohesive
- These properties vary among types and physical and chemical properties
- Reliability of operation is a function of = Material handling & logistics, safety, Cost (capital to operate) and quality performance
- The role of preprocessing is not grinding or drying or densifying. It is to produce a consistent feedstock



Conversion-Ready Feedstock Supply

Developing a new
uniform format
advanced supply
system design

**ADVANCED
PREPROCESSING**



FEEDSTOCKS

Improving the capacity
and efficiency of each
feedstock logistics unit
operation



**UNIFORM
FORMAT
TARGETS**



Conversion-Ready Feedstock Properties

Predicted Performance

Stover Pellet
Meal



¼ minus
Stover



10-ft Bin Diameter 2-ft Opening	Advanced Material	Corn Stover	
Flow Rate (lb/min)	2432	345	↑
Feed Density (lb/ft³)	26.9	7.4	↑
Bin Density (lb/ft³)	30.0	9.1	↑
Compressibility (%)	12.8	28.1	↓
Permeability (ft/sec)	0.24	0.18	↑
Springback (%)	3.76	4.72	↓
Hausner Index	1.13	1.28	↓
Cohesion (kPa)	3.83	6.61	↓
Angle of Repose	39.2°	35.3°	↓
Flowability Factor	5.8 easy flowing	1.2 very cohesive	↑

↑ or ↓

Indicate desired
direction of
change

Truck Load of Barley Straw Pellet Meal



Other Preprocessed Products:

- Fractionated (Stover Fiber)
- Thermal Treated
- Various Densification Formats
- Blended



Preprocessing solutions

Equipment Engineering Solutions

- Improve the design of biomass processing and handling equipment
 - Designed to biomass material properties
 - Robust to handle variability

Control System Solutions

- Develop control systems that monitor and adjust processing conditions to maintain consistent production rate and feedstock quality
- Examples
 - Reactive Control: Maintain constant mass flow
 - Adaptive Control: Maintain feed specs as infeed properties vary

Material Engineering Solutions

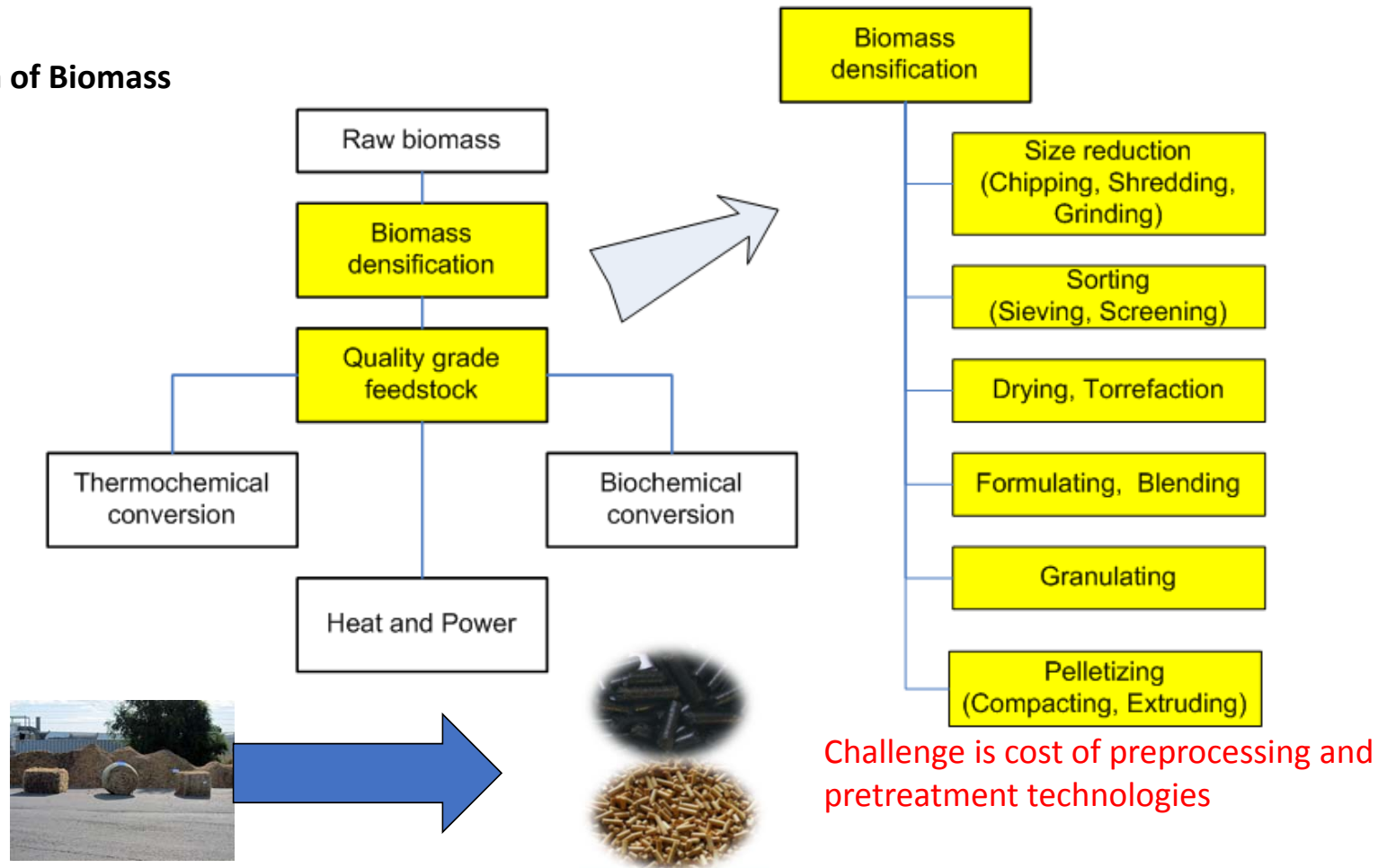
Insert processes to alter biomass material properties and enable use of existing equipment

- Examples
 - Densification: compressible, elastic behavior
 - Flow Additives: cohesiveness
 - Heat Treatment: mild deconstruction of cell structure to alter properties



Transforming raw biomass to quality feedstocks

Densification of Biomass



Some advanced preprocessing technologies

Fractional milling: Increase screen size of stage-1 grinder and insert separator between stage-1 & 2 grinding operations to bypass fraction which meets stage-2 grinder specs

- Avoids redundant preprocessing and saves energy.
- Tighter particle size distribution with reduced fines.

High-moisture pelleting: Biomass is pelleted at moistures 18-30% (w.b.).

- Biomass loses moisture (5-10%, w.b.) due to preheating & frictional heat in the die
- Drying is optional (pellets can be dried only when highly durable and aerobically stable pellets are needed).

Low-temperature drying: High-moisture pellets can be dried using grain and belt dryers

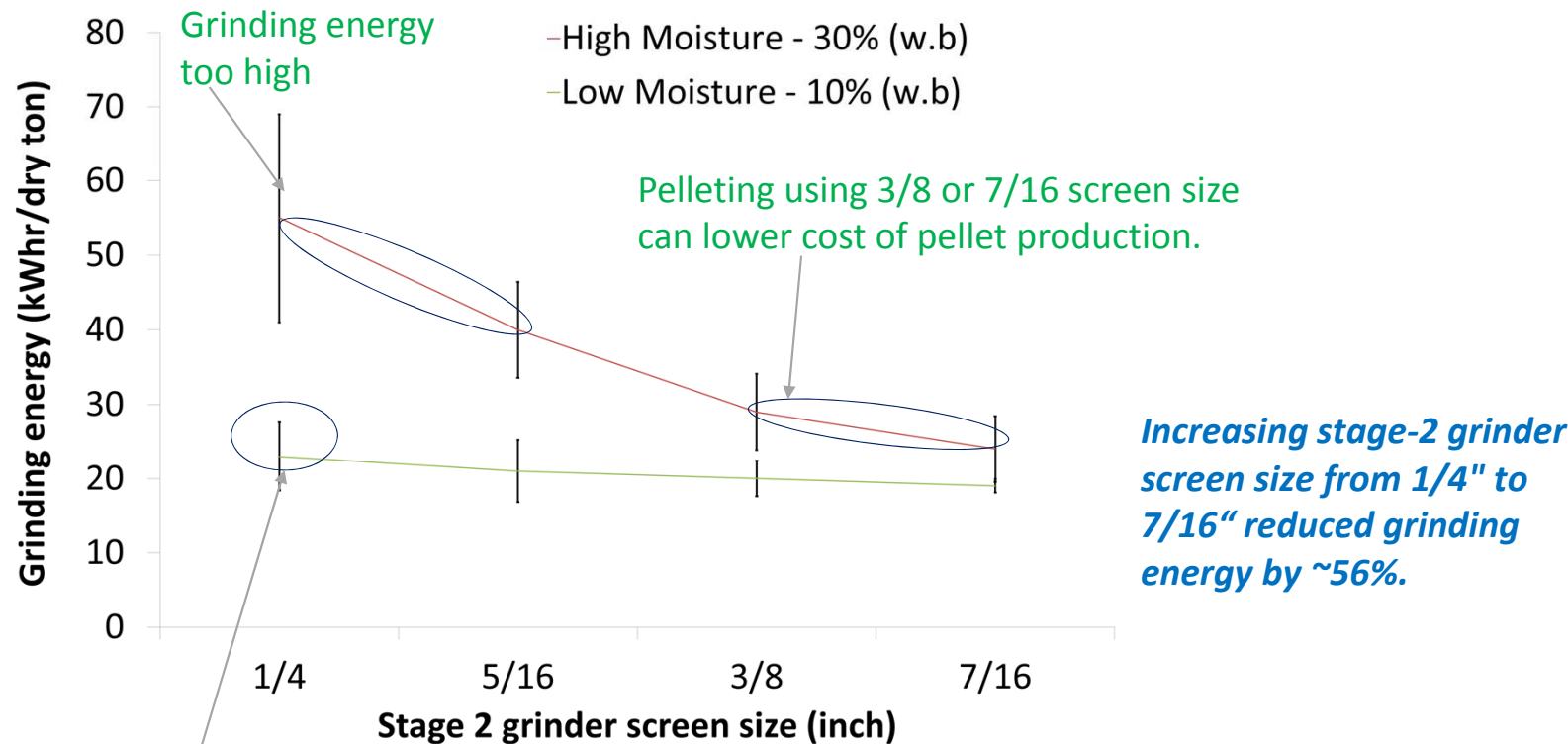
- Less energy and capital intensive
- Eliminates the volatile organic emissions during drying

Combined torrefaction and pelletization

- Reduces the densification cost,
- Produces higher quality torrefied densified products



Fractional milling



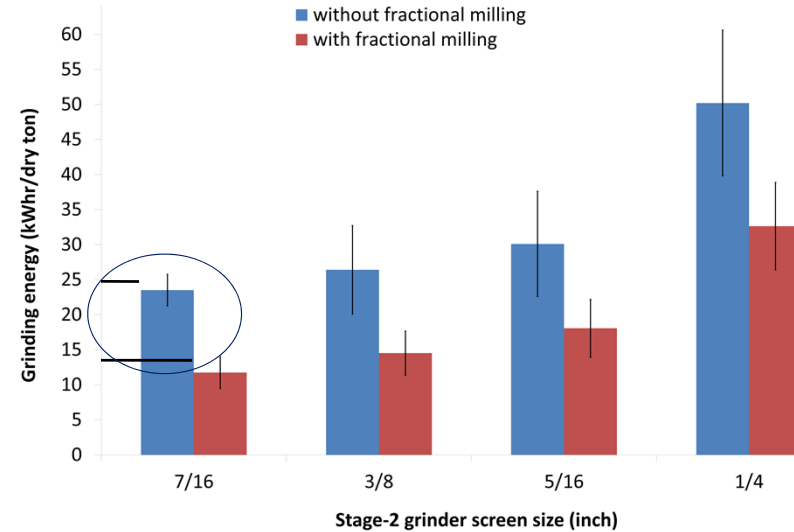
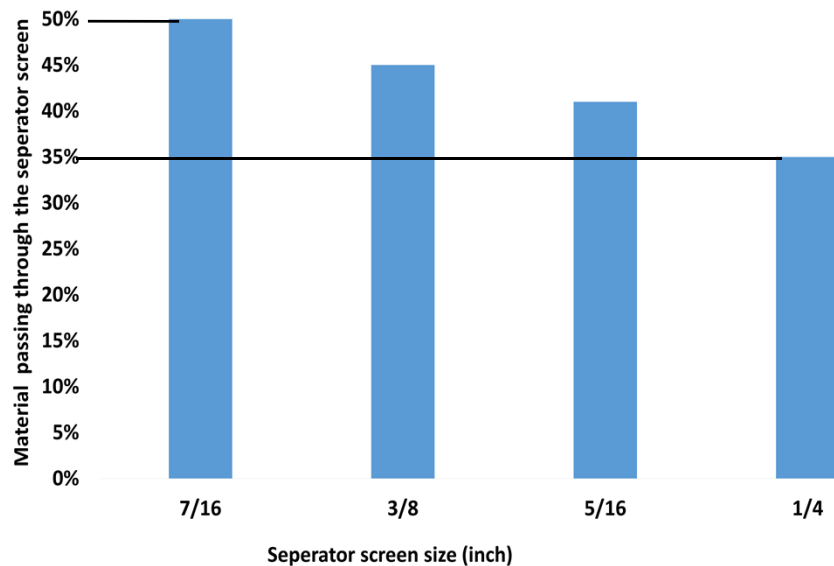
Industry pelleting standard of 1/4 inch works well for low moisture content (10%, w.b.) as the grinding energy does not change significantly with the screen size. But at high moisture, the grinding energy increases exponentially.



Fractional milling

Fractional milling can reduce impact of screen size and moisture content on stage-2 grinder

For 1/4 inch the separation efficiency is about 35%, whereas for 7/16 it is about 50%.

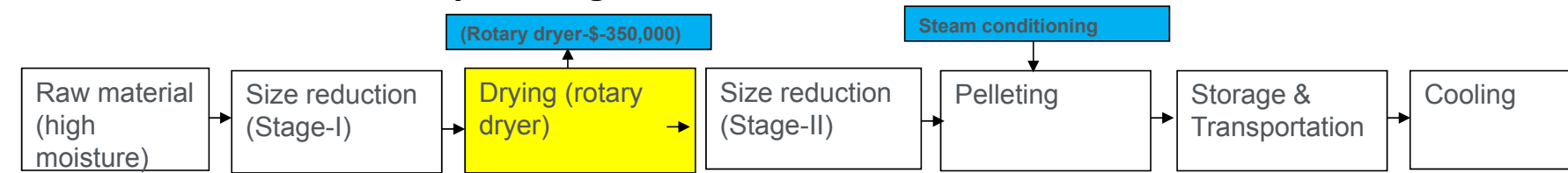


There is about 65% decrease in grinding energy using 7/16 inch screen compared to 1/4 inch screen with fractional milling.

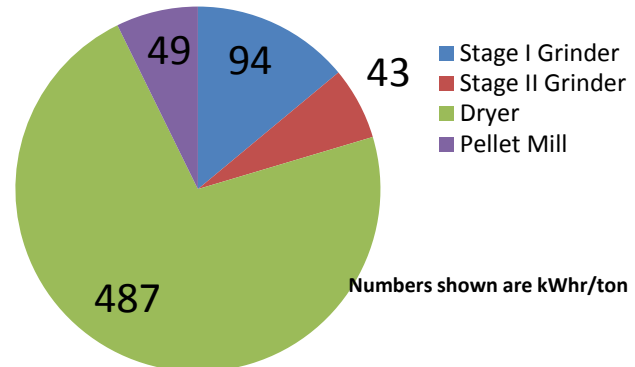
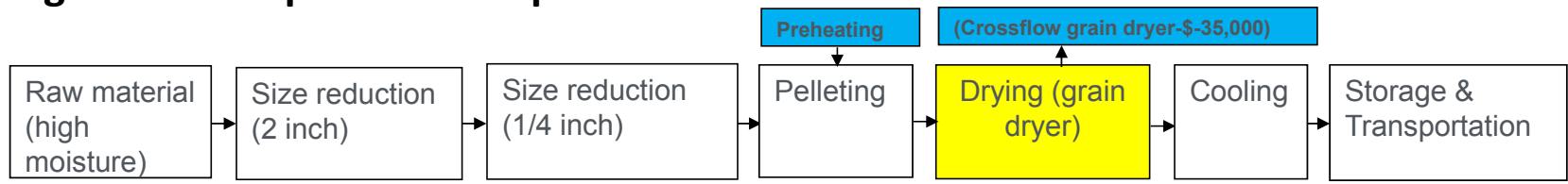


Conventional versus High moisture pelleting

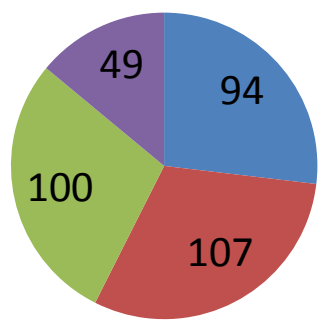
Corn stover-Conventional pelleting



High-moisture pelletization process for corn stover



Conventional pelletization process



High moisture pelletization process

Pelleting process	Total energy (kWhr/ton)
Conventional	672
High moisture	350

High moisture pelleting-Advantages

- Process heat developed in the pellet die is utilized to partially dry the biomass during pelleting.
 - There is a **decrease of 5-10% of moisture** in the biomass during pelletization
- Partially dried pellets can be dried using low cost and energy efficient dryers (such as grain or belt dryers) operate at low temperature (60–80°C)
 - **No volatile organic emissions during drying**
 - Reduced risk of fire and explosion
 - **Low quality heat can be used for drying**
 - Better control over the product moisture
 - **Less capital intensive**
 - **Less energy required for drying**
- Pellets have no recalcitrance for biochemical conversion.



Techno-economic analysis

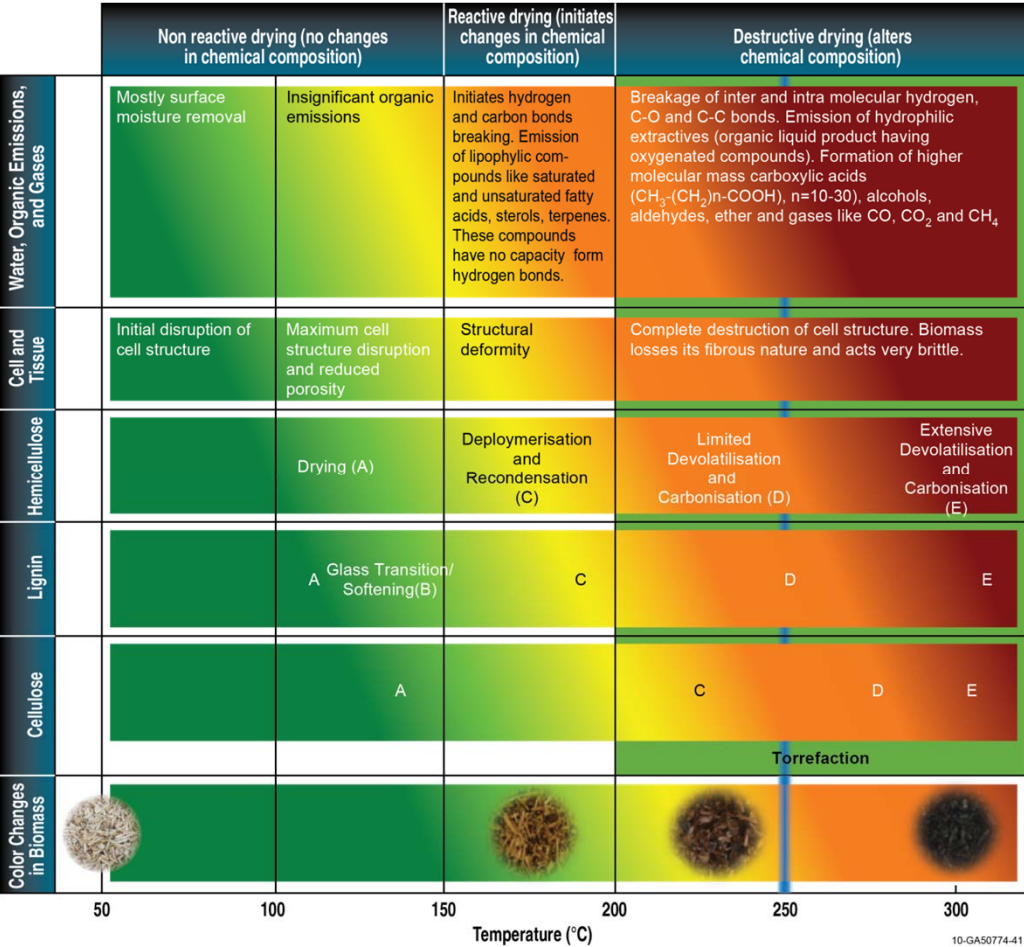
Preprocessing cost of corn stover bales at 30% moisture content

	Cost (\$/dry ton)	Quality of pellets
Current pelleting cost for herbaceous biomass	62.00	Bulk density: 640 kg/m ³ Durability: 98.5% (Yancey et al., 2013)
Preprocessing cost targets achieved with fractional milling high moisture densification and low temperature drying		
Case-1 (stage-2 grinder fitted with 1/4-inch screen)	29.09	Bulk density: 608 kg/m ³ Durability: 97.6%
Case-2 (stage-2 grinder fitted with 5/16-inch screen)	27.66	Bulk density: 585kg/m ³ Durability: 98.3%
Case-3 (stage-2 grinder fitted with 3/8-inch screen)	27.17	Bulk density: 573 kg/m ³ Durability: 98.4%
Case-4 (stage-2 grinder fitted with 7/16-inch screen)	25.35	Bulk density: 545 kg/m ³ Durability: 98.4%

Fractional milling, high-moisture pelleting and low-temperature drying reduced pelleting cost of high moisture corn stover by about 62% compared to Current State of Technology followed by the industry



Torrefaction and densification



Drying: 200°C

Torrefaction reactions: 200–300°C

- Devolatilization and carbonization of hemicellulose
- Depolymerization and devolatilization/softening of lignin
- Depolymerization and devolatilization of cellulose.

Mass yield: ~70%

Energy yield: ~90%

Net calorific value: 18–23 MJ/kg

Moisture content: 1–2%

Hydrophobic, max: 1–6% moisture uptake.

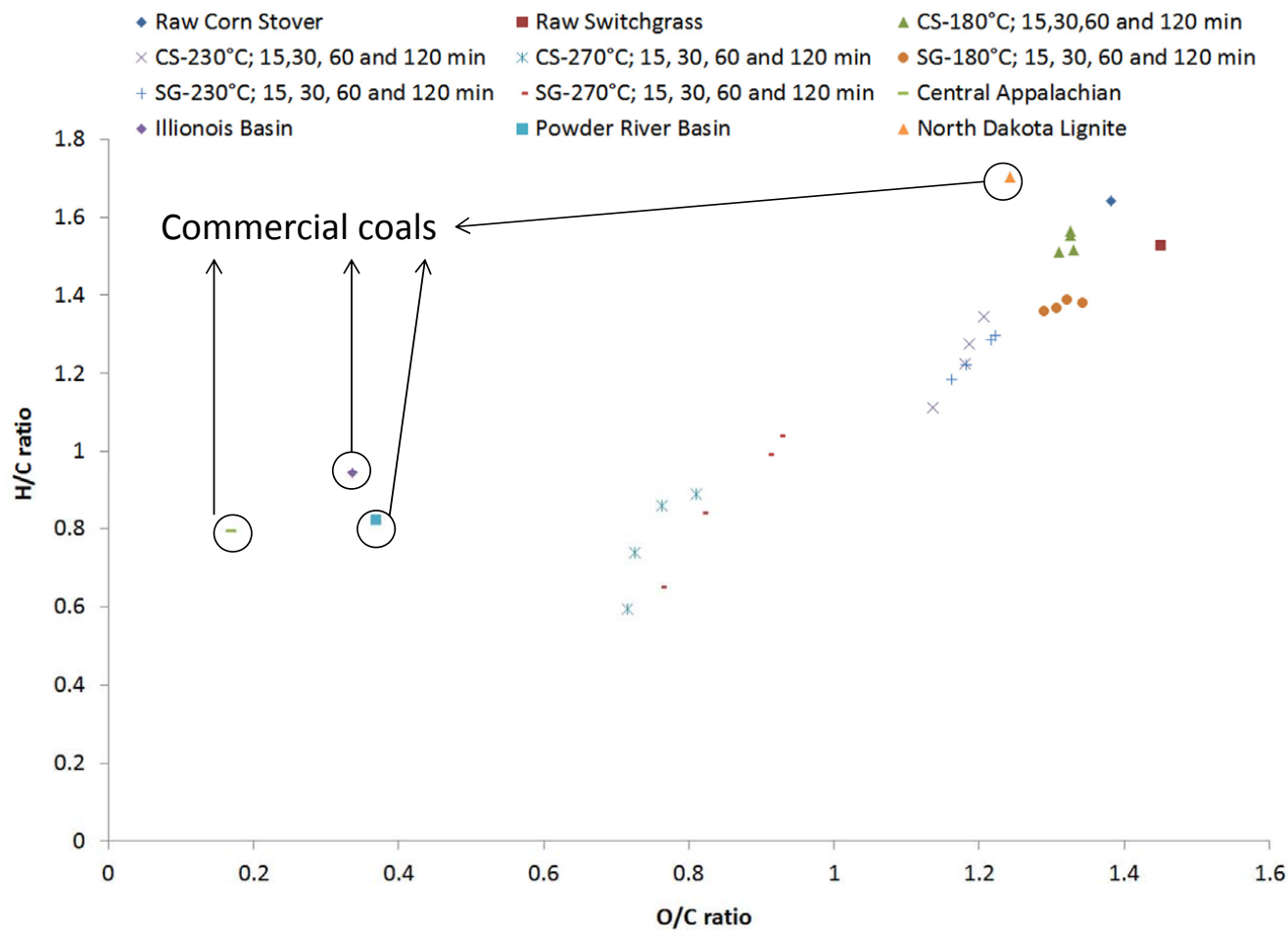
Figure 3. Structural, chemical and color changes in biomass at different temperature regimes.



Color Changes in Biomass



van Krevelen Diagram



Densification approaches of torrefied biomass



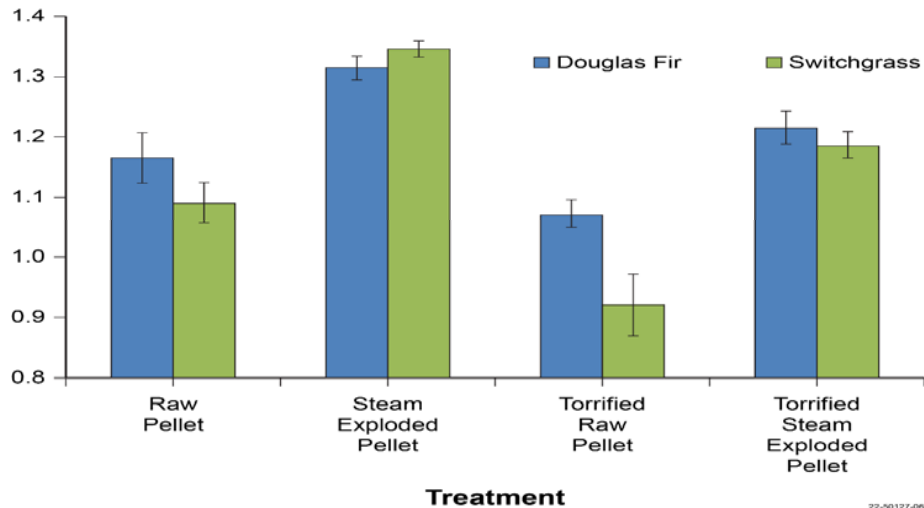
Two process configurations.

- Pathway I consist of torrefying wood chips and then turning the wood chips into pellets. In
- Pathway II, commercial pellets are heat-treated to make torrefied pellets.



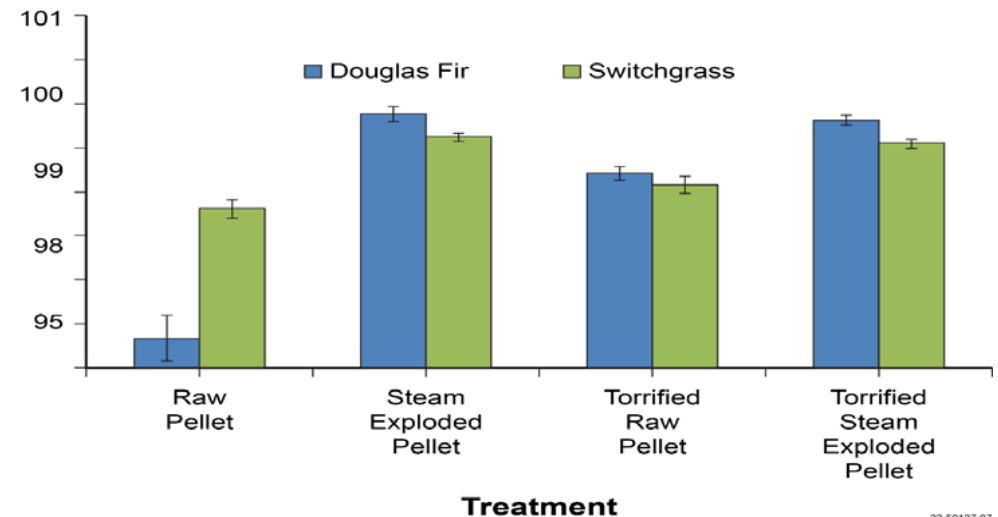
Thermal pretreatment impact on pellet quality

Single pellet density of woody and agricultural biomass after different treatment



22-50127-06

Durability of woody and agricultural pellet after different thermal treatment



22-50127-07

Forthcoming

Densification Impact on Raw, Chemically and Thermally Pretreated Biomass
Physical Properties and Biofuels Production

Editor: Michael Gatzert
Editor: Jaya Shankar Tumuluru

Wiley Science

Sustainable Chemistry Series: Volume 6

Densification Impact on Raw, Chemically and Thermally Pretreated Biomass

Physical Properties and Biofuels Production

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Summary

Feed handling problems blamed for slow start-up majorly due to inadequate understanding of the behavior of particle systems.

Moisture, particle size and foreign matter create feed handling problems at upstream feedstock handling and downstream conversion operations.

Particle system is like to be less consistent than consistent and does not scale-up

Commercial biorefineries have indicated difficulties in handling agricultural residue bales such as corn stover.

Decoupling the feedstock conversion from conversion helps to reduce the downtime.

The focus of preprocessing should be to produce a consistent feedstock.

Preprocessing solutions can include equipment engineering, control system or material engineering solutions.

Advanced preprocessing technologies help to reduce the preprocessing cost significantly.

