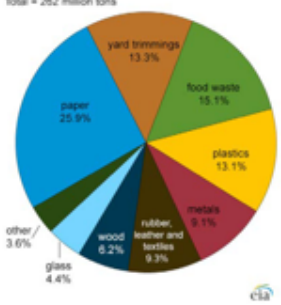
QbD Case Study: Densification of Municipal Solid Wastes and Residues

Jordan Klinger, Ph.D.

Idaho National Laboratory
February 19, 2020

Advancing the Bioeconomy: From Waste to Conversion-Ready Feedstocks Workshop

MSW processing pathway – a focus on variability mitigation through preprocessing



High Variability

CMA

.....

.....

.....

...

Preprocessing

Lower Variability

CMA

.....

...

Conversion

CQA

.....

Product

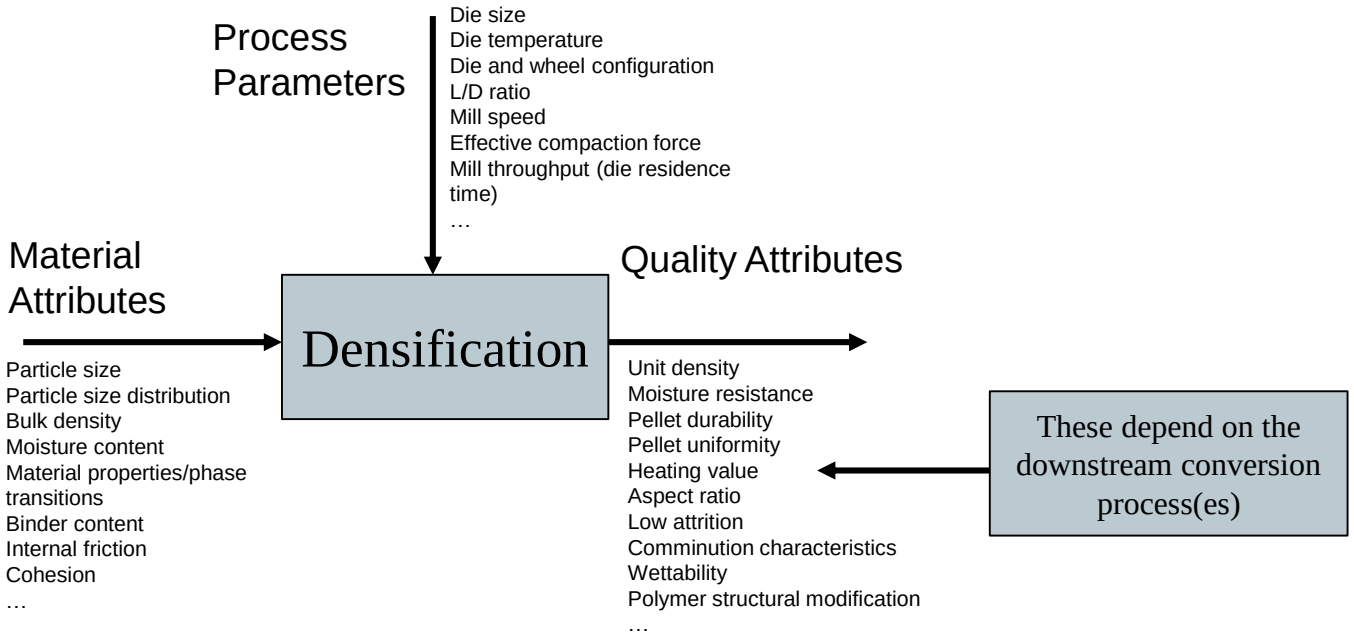
https://www.energy.gov/sites/prod/files/2019/08/f66/BETO--Waste-to-Energy-Report-August--2019.pdf

Advanced Preprocessing and Fractionation: Addressing Feedstock Variability

- Mechanical Separation
  - Use screen, gravity table, air classification to separate materials by size, shape, buoyancy, density or color, surface characteristics, and other physical properties
- Chemical Separation
  - Washing with water, or leaching with acid/alkali to remove alkali metals/alkaline earth metals, cell-bound nitrogen, sulfur, and soluble inorganics and improve quality
- Advanced Fractionation and Automated Sorting
  - Use a variety of sensors to identify differential characteristics
    - Visible light, UV, IR, XRF, etc.
  - Particles of interest are sorted using pneumatic jets, levers, or robotic mechanisms
- Densification *Case study focus*
  - Many potential technologies: flat die mill, ring-die mill, briquetter, cuber, extruder, bagger, etc.
  - Defines a unit of feedstock from a very complex mixture with diverse chemical/physical properties
  - Improve the bulk and energy density for cost-effective transportation and conversion
  - Improve flow properties for uniform and reliable flow and feeding into reactors
- Blending and Formulation
  - Allows to incorporate low-quality, low-cost resources (non-recyclable/waste) and achieve the required in-feed specifications for conversion
  - Offers the potential for feedstock quality upgrades and reduced variability

Addressing QbD in MSW Densification

Quality-by-Design (QbD) provides a scientific structure to the study of complex systems and helps determine which material attributes and process parameters are critical to achieve desired outcomes

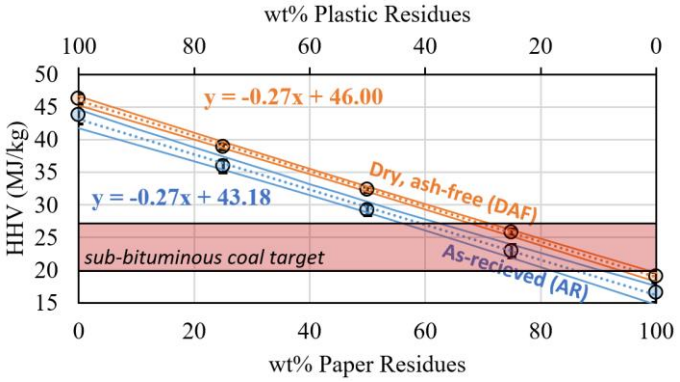


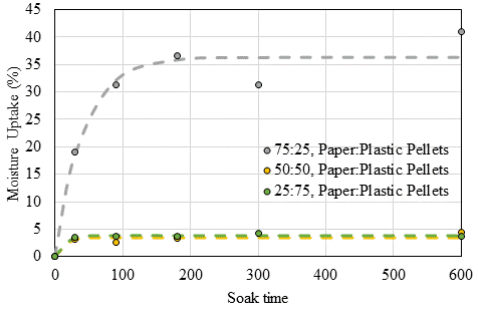
In this case study, the desired product was a high-energy fuel pellet and the **critical quality attributes** (CQAs) **were high heating value, durability, and moisture resistance** of the pellets

Observed Material Attributes Variability from Diverse Resources

- Highly variable initial material attributes (i.e., moisture, ash,) influenced by the ratio of mixed fiber (paper, cardboard, wax paper) to plastic (PP and PE) waste.

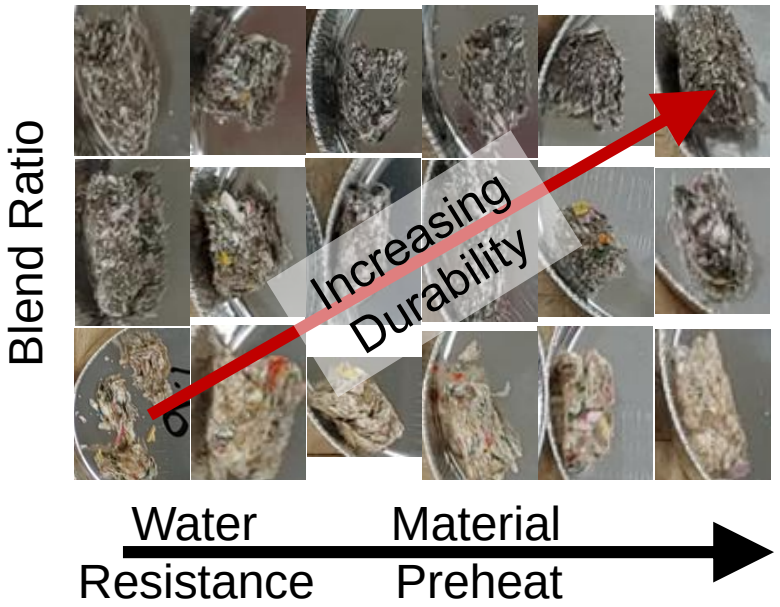
Sample	Paper (wt%, AR)	Plastic (wt%, AR)	Moisture (wt%, AD)	Ash (wt%, D)
1	0	100	0.13	5.23
2	0	100	0.21	5.39
3	100	0	4.94	9.00
4	100	0	4.94	9.07
5	50	50	2.51	7.26
6	50	50	2.57	7.23
7	25	75	1.35	6.33
8	25	75	1.25	6.33
9	75	25	3.54	7.99
10	75	25	3.45	8.06



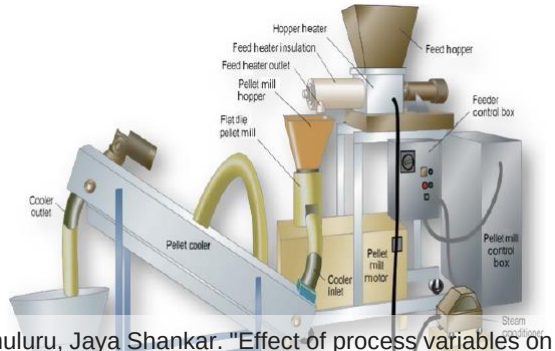


Identifying Critical Processing Parameters of Material Preheat and Die Aspect Ratio

- Tested Processing Parameters (PPs):
  - die length,
  - die diameter,
  - material preheat conditions,
  - feed rate
- *Determined CPPs:*
  - die aspect ratio
  - material preheat temperature



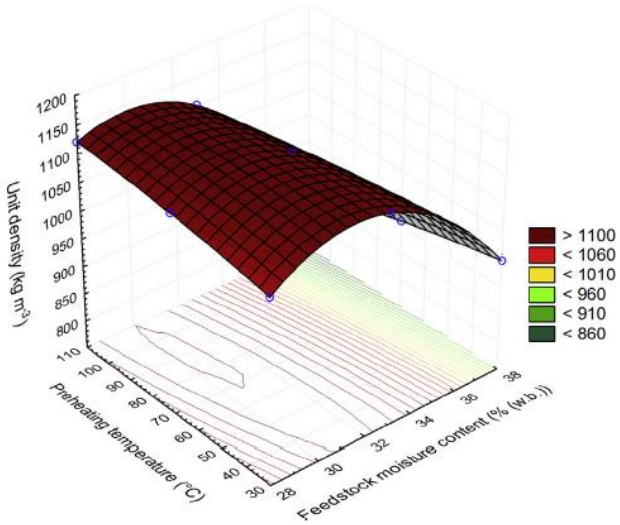
Durable12mm pellets produced at varying paper:plastic ratios

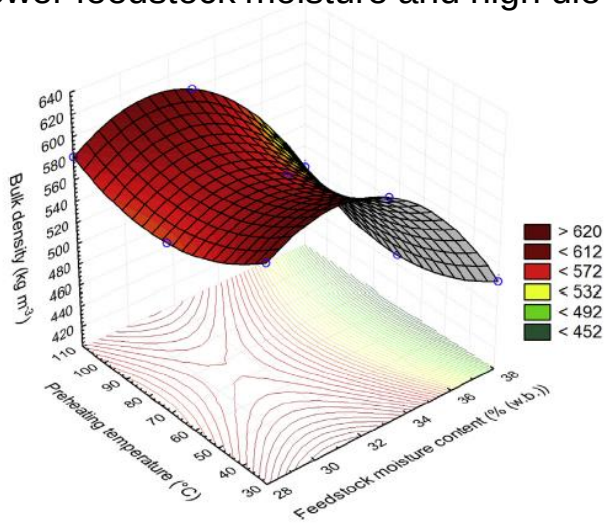


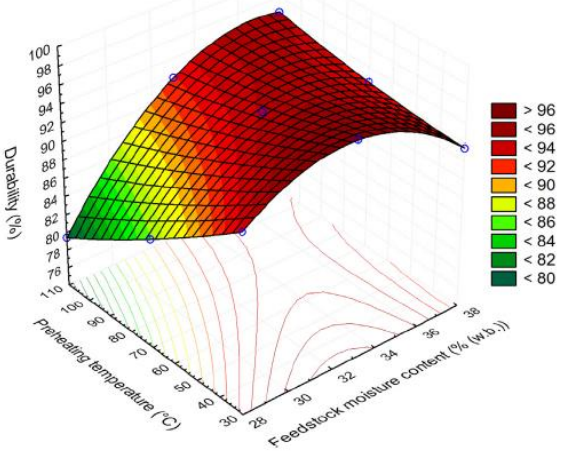
Tumuluru, Jaya Shankar. "Effect of process variables on the density and durability of the pellets made from high moisture corn stover." *Biosystems engineering* 119 (2014): 44-57.

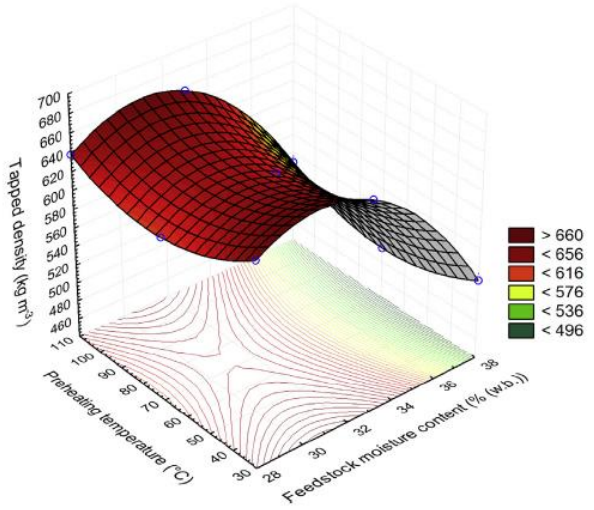
Criticality of Material Attributes in a Flat-die Mill

- Fundamental understanding is critical
  - Identified CMAs (i.e., moisture content), and CPPs (i.e., die preheater temperature)
  - The CQAs, i.e., unit density, is maximized at lower feedstock moisture and high die temperature





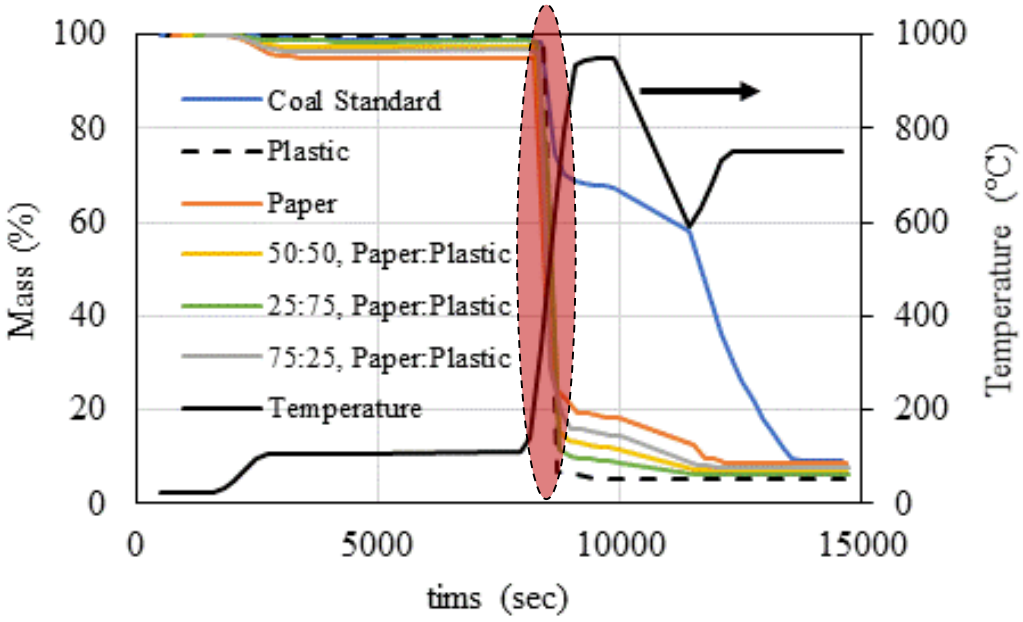


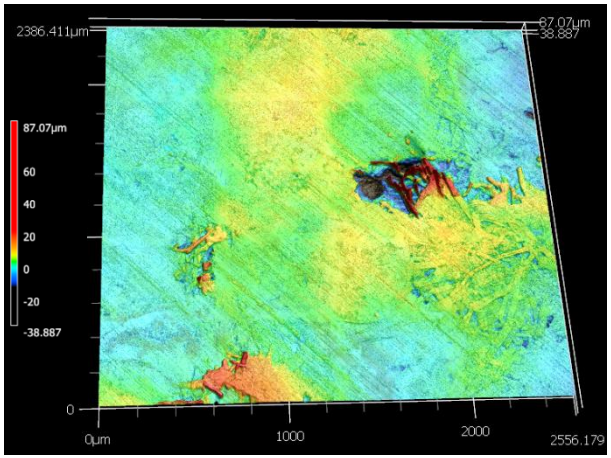


Tumuluru, Jaya Shankar. *Biosystems engineering* 119 (2014): 44-57.

Interactions Between CMAs Alters CQAs

Binder temperature-mobilization regime

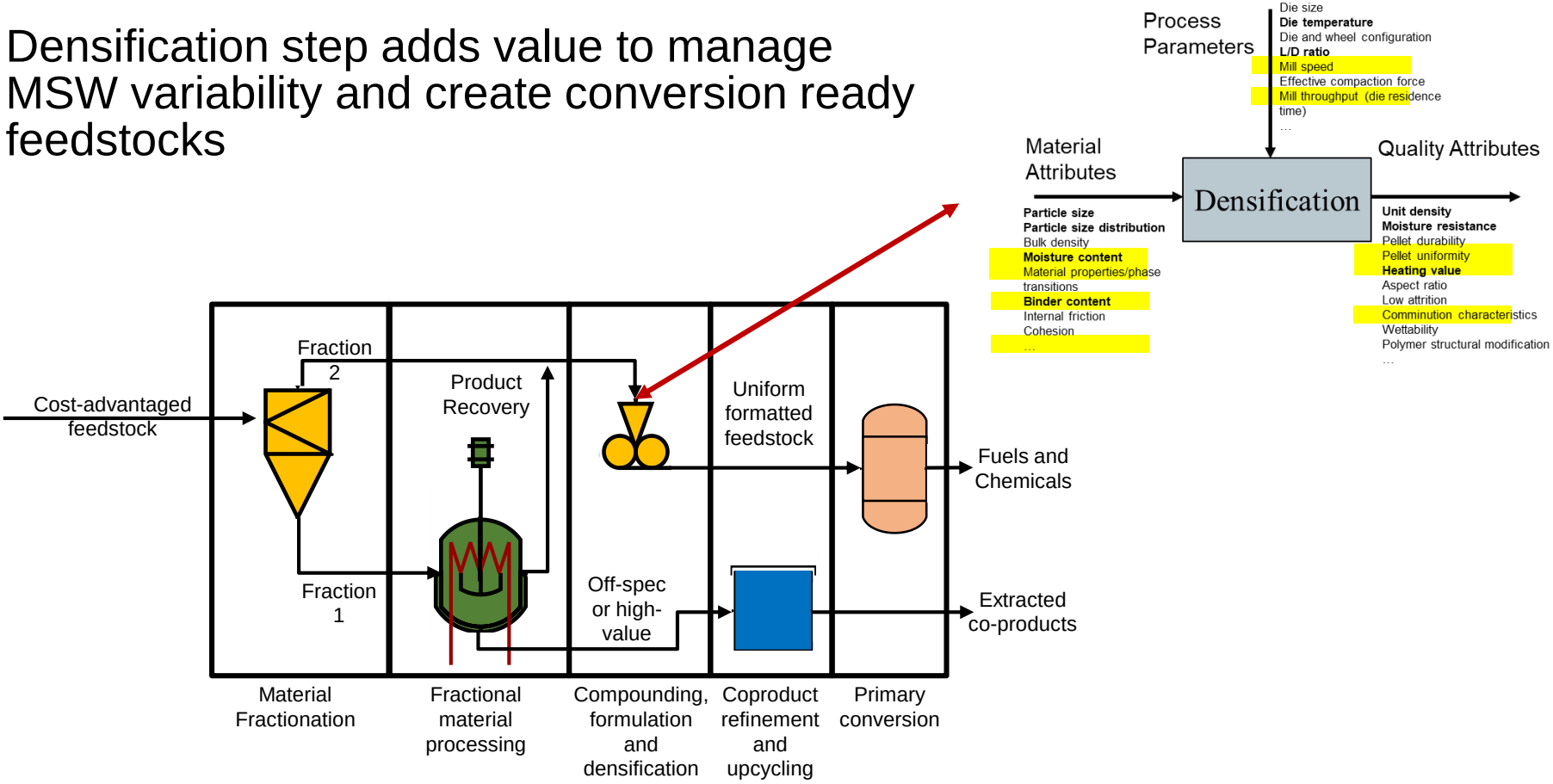




- At the proper blending ratios and processing temperatures, plastic acts as an **effective binder** and weather (moisture) repellant.
- This helps the pellets achieve over 90% durability and <5% moisture uptake (critical product attributes).
- Quality by Design helps establish product properties as functions of MAs and PPs to achieve optimized and desired quality

QbD for Fundamental Process Understanding

Densification step adds value to manage MSW variability and create conversion ready feedstocks



Following a QbD paradigm increases the fundamental knowledge and control of a production process and identifies, then focuses on, critical material attributes and process parameters.

Acknowledgements and questions

Questions?

- BETO's Feedstock Conversion Interface Consortium uses fundamental QbD approach to solve the challenges of feedstock variability. The author would like to acknowledge the contributions, review and feedback from Chenlin Li, Vicki Thompson, Luke Williams, Sergio Hernandez, Matthew Dee, Eric Fillerup, Jaya Tumuluru, and Zia Abdullah Researchers would like to acknowledge the funding support from DOE, BETO, under the general operations contract DE-AC07-05ID14517.