

October 1, 2026

Nepu Saha¹, Jordan Klinger¹, Yidong Xia¹, Zach El Zahab², Pedro Ortiz-Toral²

¹Idaho National Laboratory, Idaho Falls, ID 83415, USA

²GTI Energy, Des Plaines, IL, 60018, USA

Densification–Torrefaction–Pulverization Improves Biomass Feedstock Properties for Entrained-Flow Gasification

tcbiomass 2026, Denver, Colorado

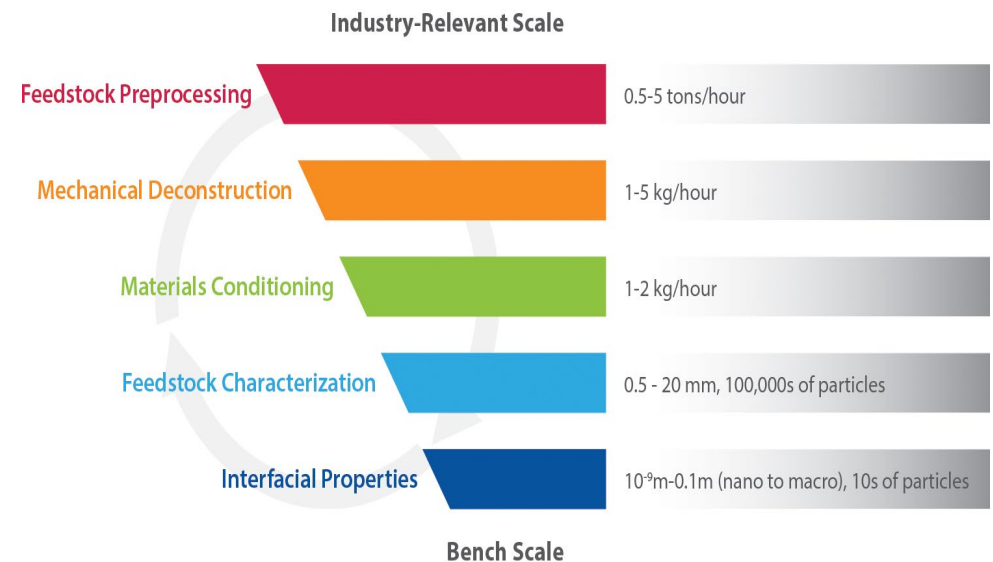
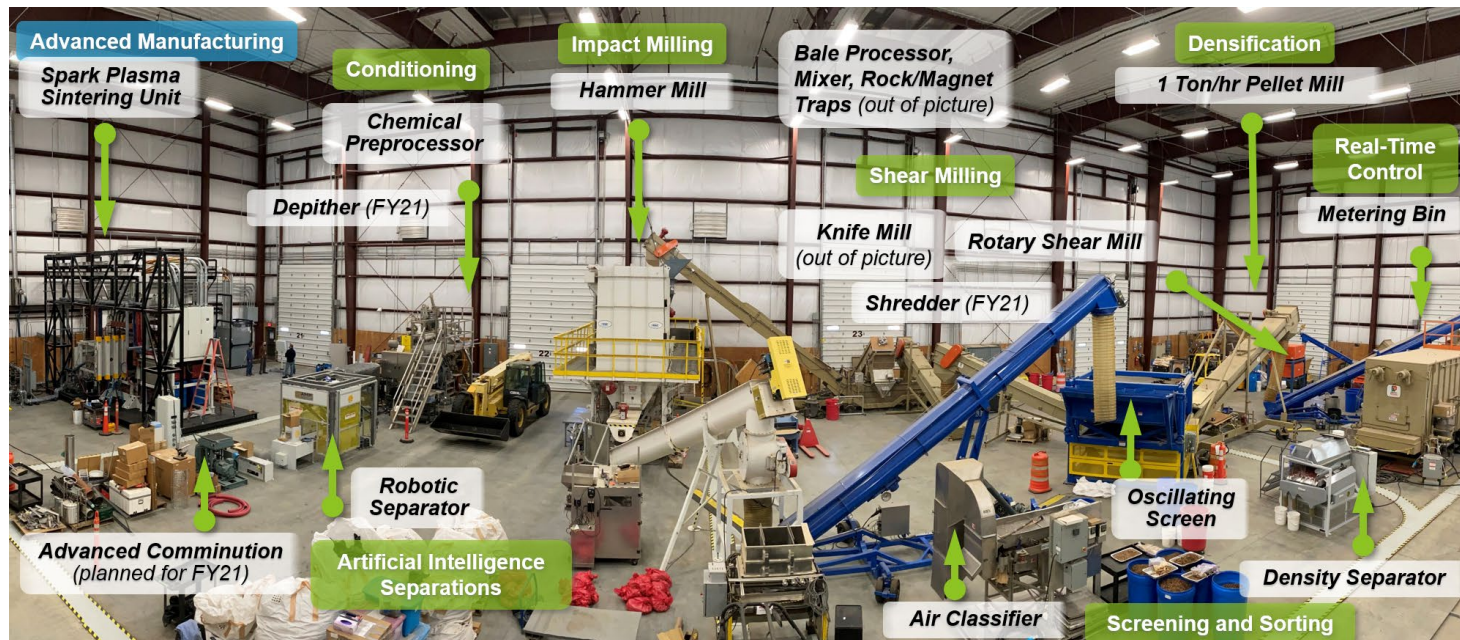
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Introduction to the Biomass Feedstock National User Facility (BFNUF)

- A **national asset** to de-risk the scale up of the biorefinery, transforming diverse carbon sources and wastes into feedstocks for specific conversion processes.
- **Bioenergy Research:** At the INL bioenergy research group focuses on R&D associated with key technical barriers facing the U.S. bioenergy and manufacturing industry.



Material Handling Challenges

Early lessons learned from industry:
poor flowability of simple ground
and dried herbaceous biomass

Outcome of INL's current SOT
baseline preprocessing methods
for herbaceous biomass

Bridging in even flow bin



Bridging in drop chute



Plugged conveyor



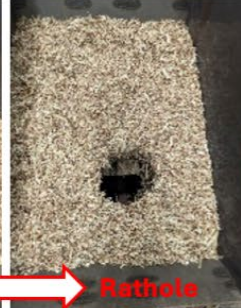
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Size reduced to 4 mm



No air classification
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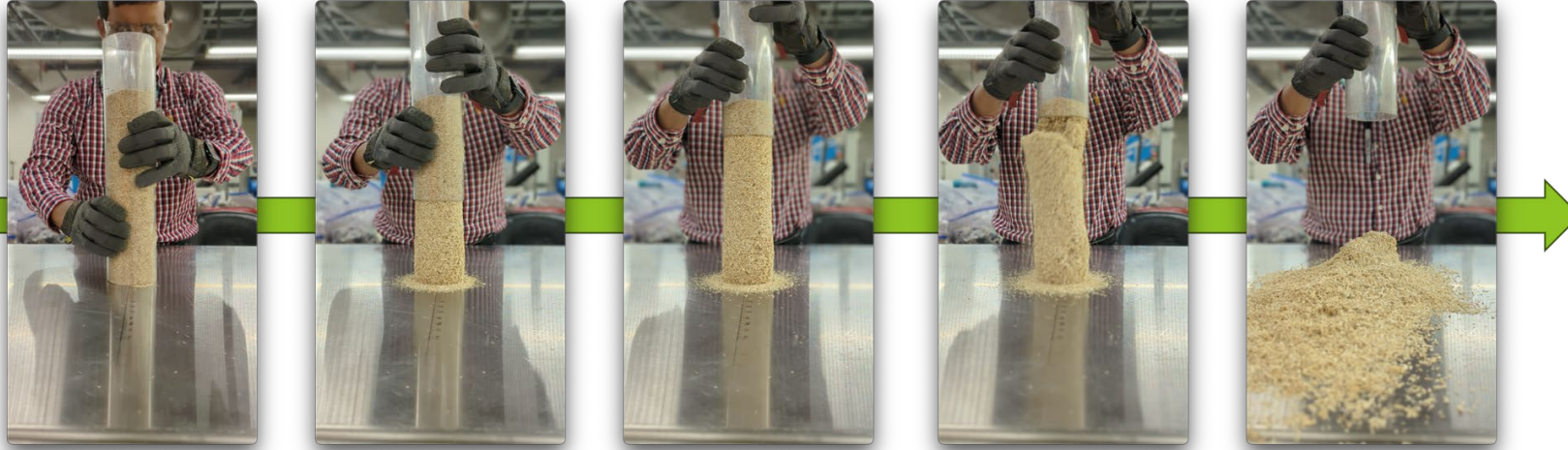
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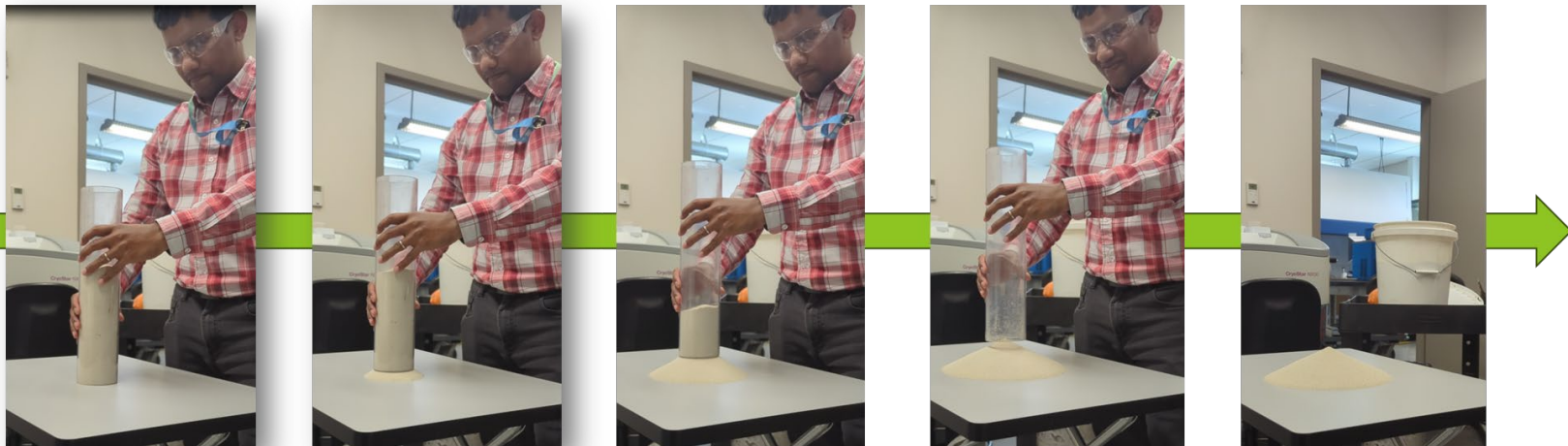
- The challenges arise primarily due to particle attributes:
 - Irregular shape,
 - High flexibility,
 - High compressibility,
- Leading to interlocking, high compaction, and consolidation.

Flowability: Angle of Repose

Miscanthus



Play Sand

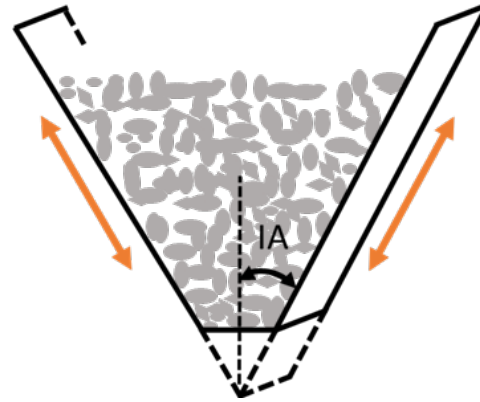


Flowability: Critical Arching Distance

Adjustable wedge hopper



Schematic of wedge hopper



Baseline materials



Rathole



Bridging



Parametric test:

- Inclination angle (IA) = 28°, 32°, 36°
- Material = Miscanthus

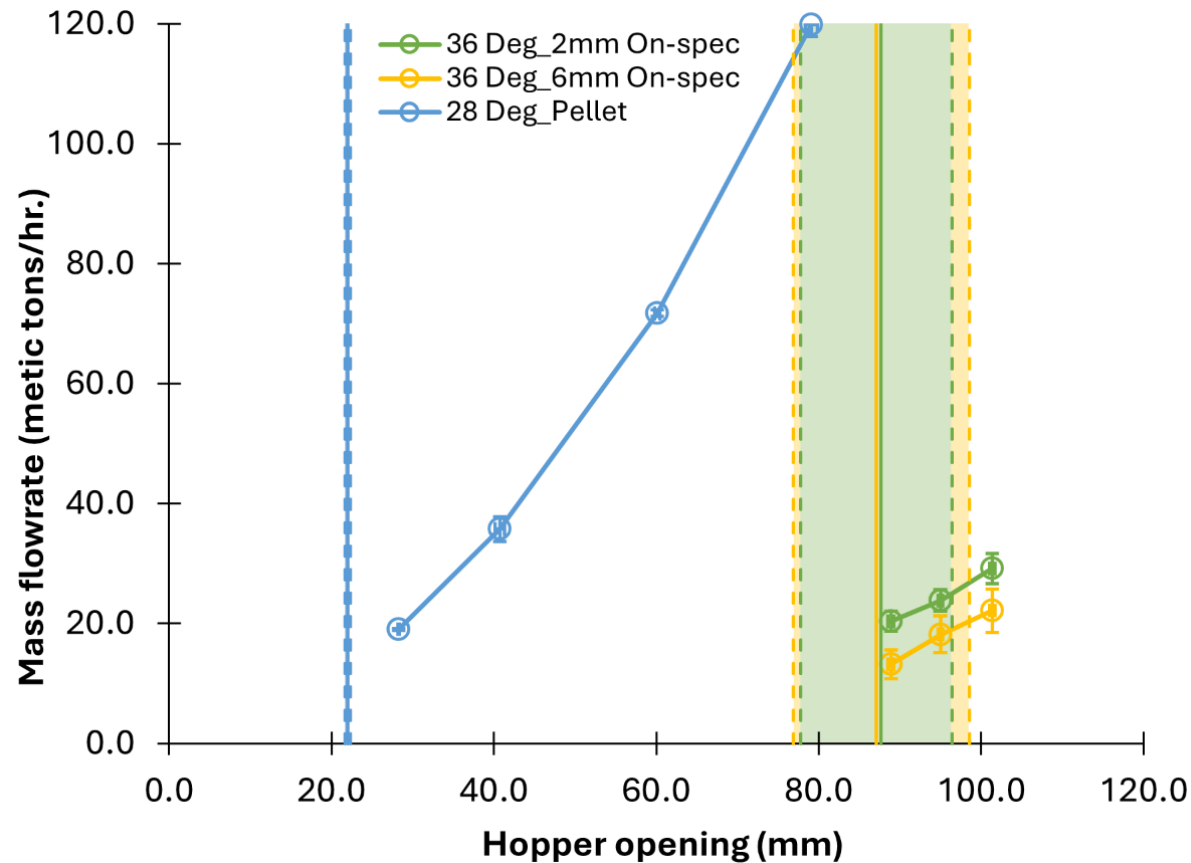
Performance metrics:

- Critical arching distance
- Flow rate (t/h)



Pelletization

Flowability: Critical Arching Distance and Flowrate



Findings:

- Pellets discharged reliably at 28° with a critical arching distance of ~22 mm (≈75% smaller than milled biomass).
- Pelletized miscanthus achieved flow rates up to 121 metric tons/hr, meeting or exceeding commercial biorefinery requirements.

Sample	IA (°)	Arching Distance (mm)		Percent Discharge (%)	Note
2 mm	28	74.6	74.5	100.0	Flow
		74.5	74.5	95.0	Flow
		79.2*	79.5*	67.0	No Flow
	32	89.2*	89.1*	44.9	No Flow
		83.6	84.0	100.0	Flow
		89.0*	89.5*	64.1	No Flow
	36	75.1	76.1	100.0	Flow
		87.2	88.1	100.0	Flow
		99.1	100.6	100.0	Flow
		87.7 ± 10.9			
6 mm	28	79.2*	79.1*	49.4	No Flow
		78.8*	78.3*	51.3	No Flow
		79.1*	79.3*	68.7	No Flow
	32	81.9	81.7	100.0	Flow
		89.1*	89.7*	55.7	No Flow
		78.2	78.1	100.0	Flow
	36	89.0*	89.3*	76.1	No Flow
		81.5	80.7	100.0	Flow
		80.9	71.4	100.0	Flow
		98.7	99.6	100.0	Flow
85.5 ± 11.2					
Pellet	28	22.1	21.7	100.0	Flow
		22.4	21.8	100.0	Flow
		23.0	21.6	100.0	Flow
		22.0 ± 0.3			
	36	22.8	22.1	100.0	Flow
		26.0	25.2	100.0	Flow
		22.5	22.0	100.0	Flow
23.4 ± 1.7					
*Maximum possible opening at that inclination angle					

*Maximum possible opening at that inclination angle

Have we solved the feeding problem?



Pyrolysis & Fluidized-Bed Reactors

Pelletization solves feeding & handling — reliable discharge, high flow rates.



Entrained-Flow Gasification

Same handling problem remains — pellets are far too coarse for this reactor.

Can we feed solid biomass into an entrained-flow gasifier?

In most cases: NO

**Refers to non-pretreated biomass (e.g., raw chips or ground).*

Biomass to Entrained Flow Gasifier

- Key properties:
 - Particle size and distribution ($<200\text{ }\mu\text{m}$)
 - Moisture content ($<10\%$)
 - Bulk density ($\sim 500\text{ kg/m}^3$)
 - etc.



Coal

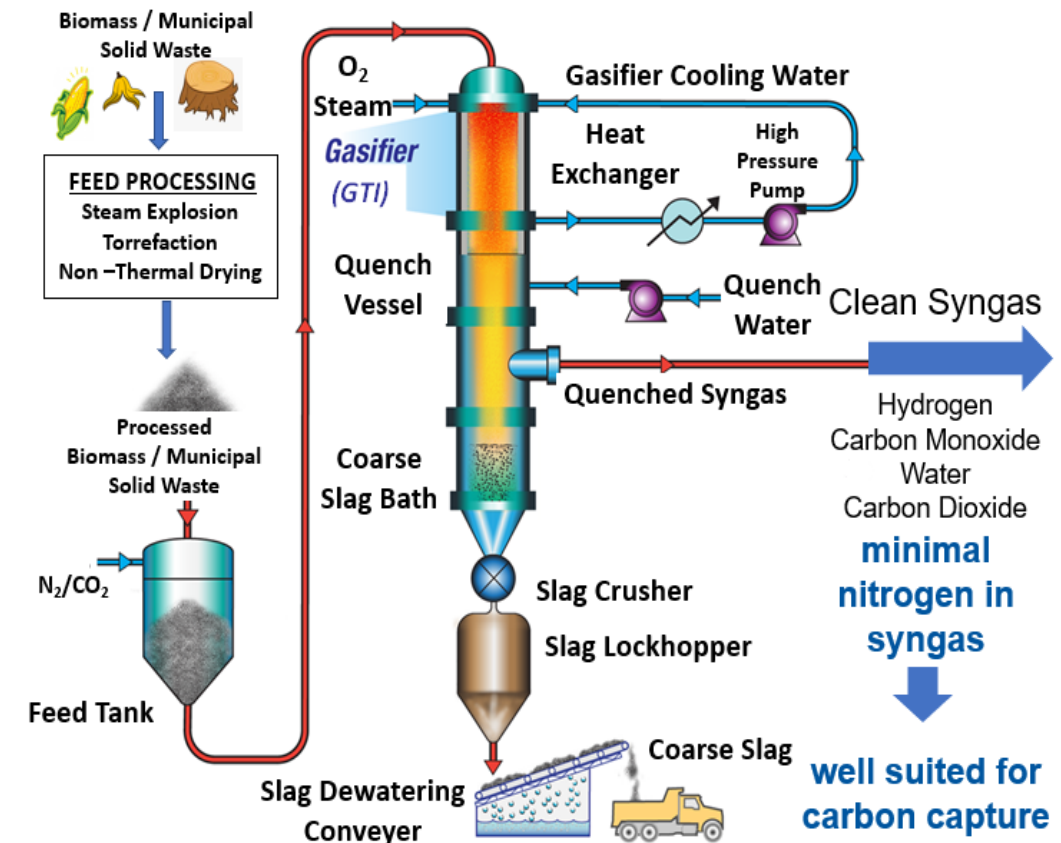


Biomass

Biomass Feed into an Entrained Flow Gasifier

AFFO (former BETO) Funded Project

- This entrained flow gasification system, called R-GAS™, was designed by GTI Energy using advanced flow principles adapted from aerospace rocket design.
- It employs a new feed delivery and transport system referred to as ultra-dense phase (UDP) feeding.
- This technology was developed around coal, and was proven to work consistently with developed specification (around coal).
- However, this project has opened a market for biomass (as solid feed) in commercial entrained flow gasifiers.



How to Tailor Biomass for Entrained Flow Gasification?

Feedstock: Corn stover

Physical properties:

Sample	Bulk density (kg/m ³)		PSD (μm)		
	Loose	Tapped	D ₁₀	D ₅₀	D ₉₀
TCS	495 ± 19	592 ± 7	64 ± 5	156 ± 11	317 ± 27
SECS	235 ± 2	280 ± 6	138 ± 27	268 ± 15	417 ± 2

Mechanical properties:

Sample	Angle of Repose (°)	Pre-shear (kPa)	Internal Friction Angle (°)	Cohesion Coefficient (kPa)
TCS	33.8 ± 1.2	10	40.09 ± 0.22	0.56 ± 0.01
SECS	35.1 ± 1.9	10	41.87 ± 0.65	0.83 ± 0.06

TCS: Torrefied Corn Stover

SECS: Steam Exploded Corn Stover

- TCS showed relatively better physical and mechanical properties compared to SECS.



Large Scale Processing Example

Corn Stover and Wood for Entrained Flow Gasification

- Collaboration with GTI Energy on BETO Scale-Up FOA award
 - Scale: ton/hr campaign, 200 tons
- Corn stover milling, densification, torrefaction, and hammer milling to achieve $<200\text{ }\mu\text{m}$
- INL rotary torrefier operates at $>\text{ton/hr}$.



Large Scale Processing Example

Corn Stover and Wood for Entrained Flow Gasification

Torrefied pellets were received in supersacks



Pellets were fed into the BFNUF PDU



Pellets were milled to <200 um



Fine milled feedstock was packaged for GTI

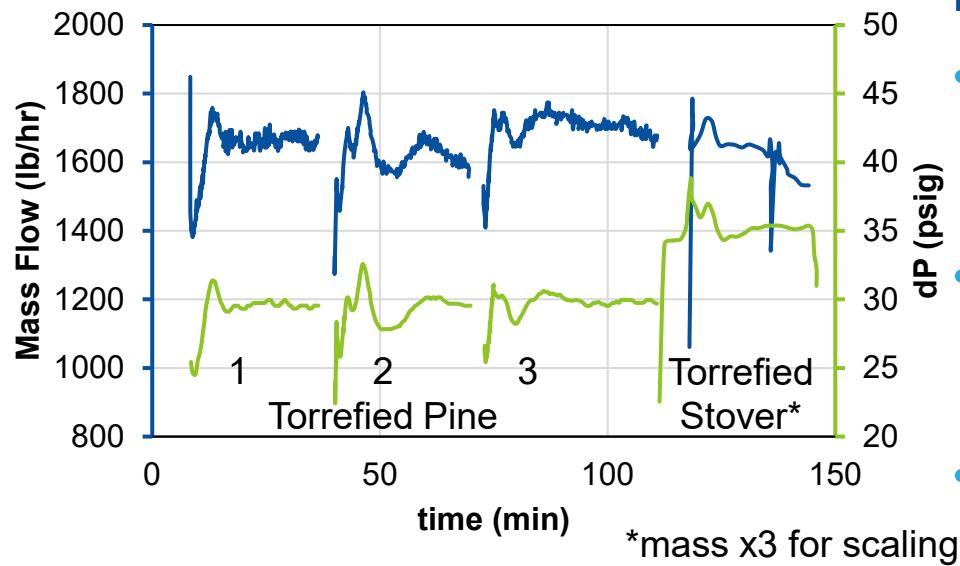


Fine torrefied corn stover was prepared and shipped to GTI to feed the entrained flow gasifier

Large Scale Processing Example

Corn Stover and Wood for Entrained Flow Gasification

- Corn stover densification, torrefaction, and fine milling to determine PSD spec for flowable biomass at pressure (>350psig) in entrained flow gasification



Key Results:

- Achieved <200um nominal particles at ton/hr scale
- Achieved stable mass flow with very low pressure drop in gasifier
- Enabled continuous ultra-dense phase feeding of gasifier

PSD	1200 μm Screen	800 μm Screen	400 μm Screen
D10 (μm)	87.8 ± 4.3	75.1 ± 5.8	72.9 ± 3.4
D16 (μm)	114.8 ± 4.9	97.7 ± 6.5	89.7 ± 4.1
D50 (μm)	239.1 ± 6.2	200.8 ± 8	158.7 ± 8.6
D84 (μm)	401.1 ± 7.6	333.8 ± 7.9	237.3 ± 15.7
D90 (μm)	452.9 ± 8.3	376.2 ± 8	260.9 ± 18.1

Can we feed solid biomass into an entrained-flow gasifier?

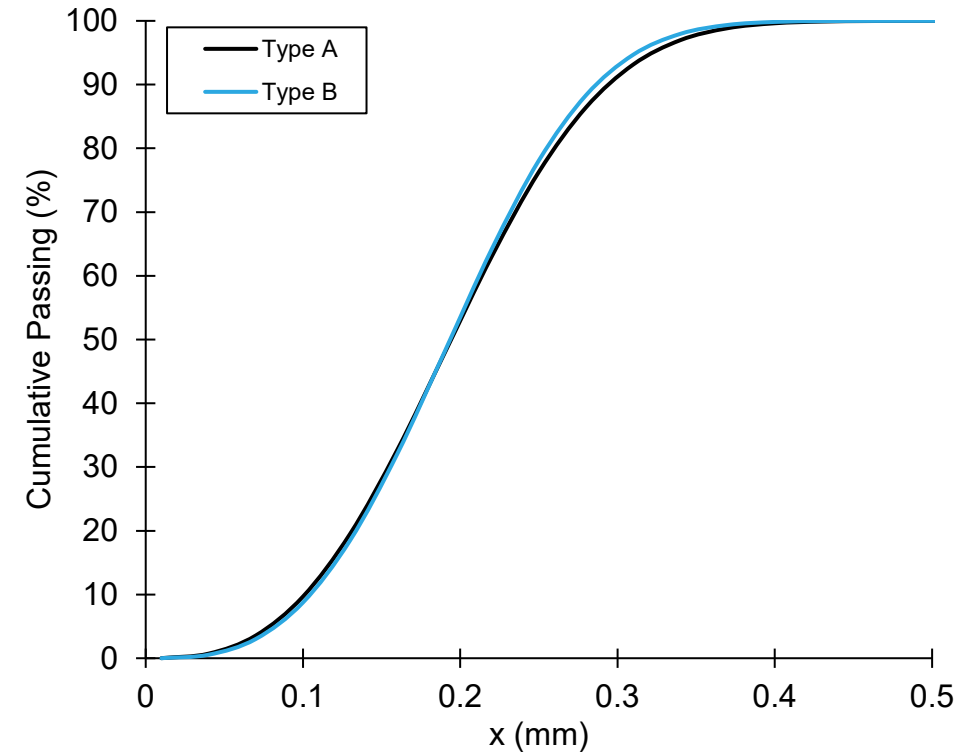


Yes, we can feed solid biomass into an entrained-flow gasifier!

Why Densification?



- PSD of both materials exhibit similarities; there is a significant divergence in their densities.
- Given that density is a critical parameter alongside particle size for successful flow into pressurized gasifier system, it is evident that densification is a necessary step in the overall processing pathway.



Sample	Density (kg/m ³)	
	Bulk	Tapped
Type A	446.3 ± 6.0	523.4 ± 2.6
Type B	225.3 ± 3.4	276.2 ± 2.8

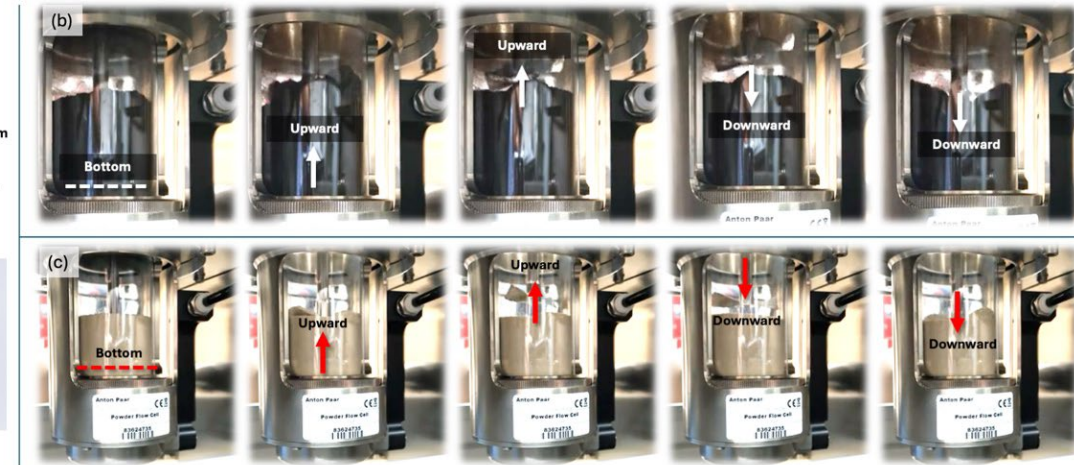
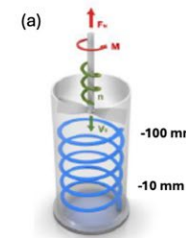
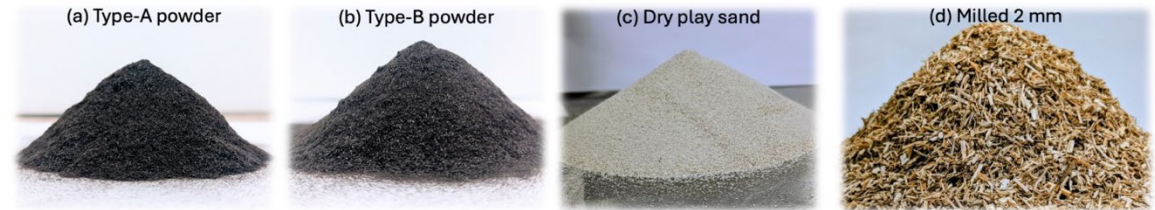
Flow Energy: Experiments

- A helical impeller moves through a packed powder bed on an Anton Paar rheometer with a Powder Flow Cell, recording torque and normal force during travel.
- Total flowability energy (W) integrates torque and normal force over the impeller's travel depth, accounting for blade radius and helix angle.

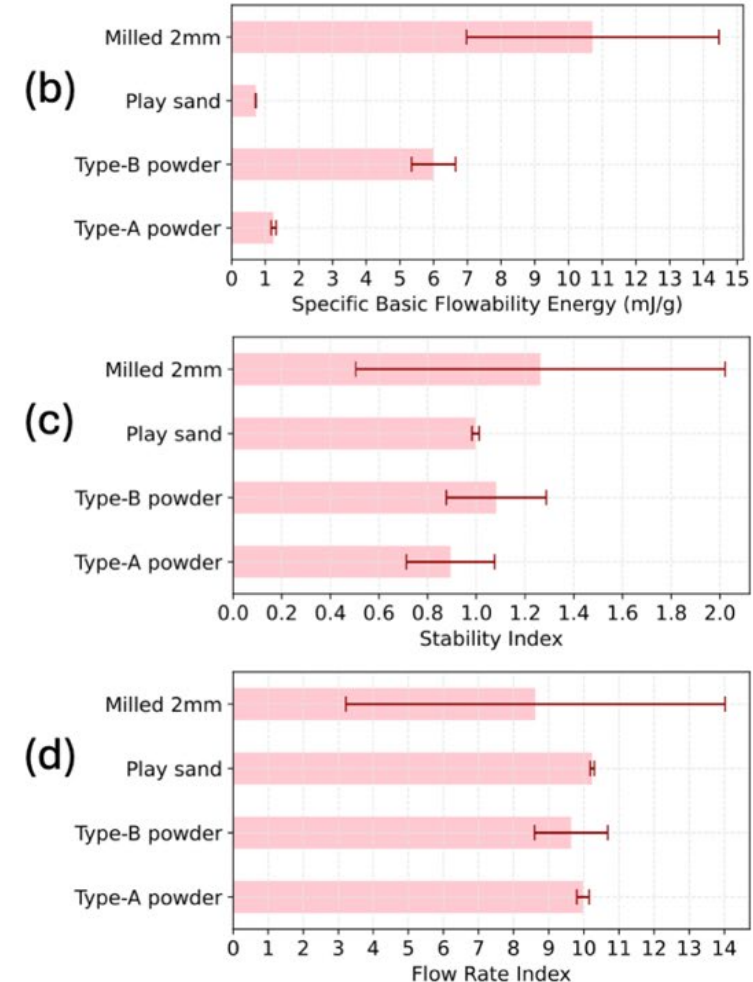
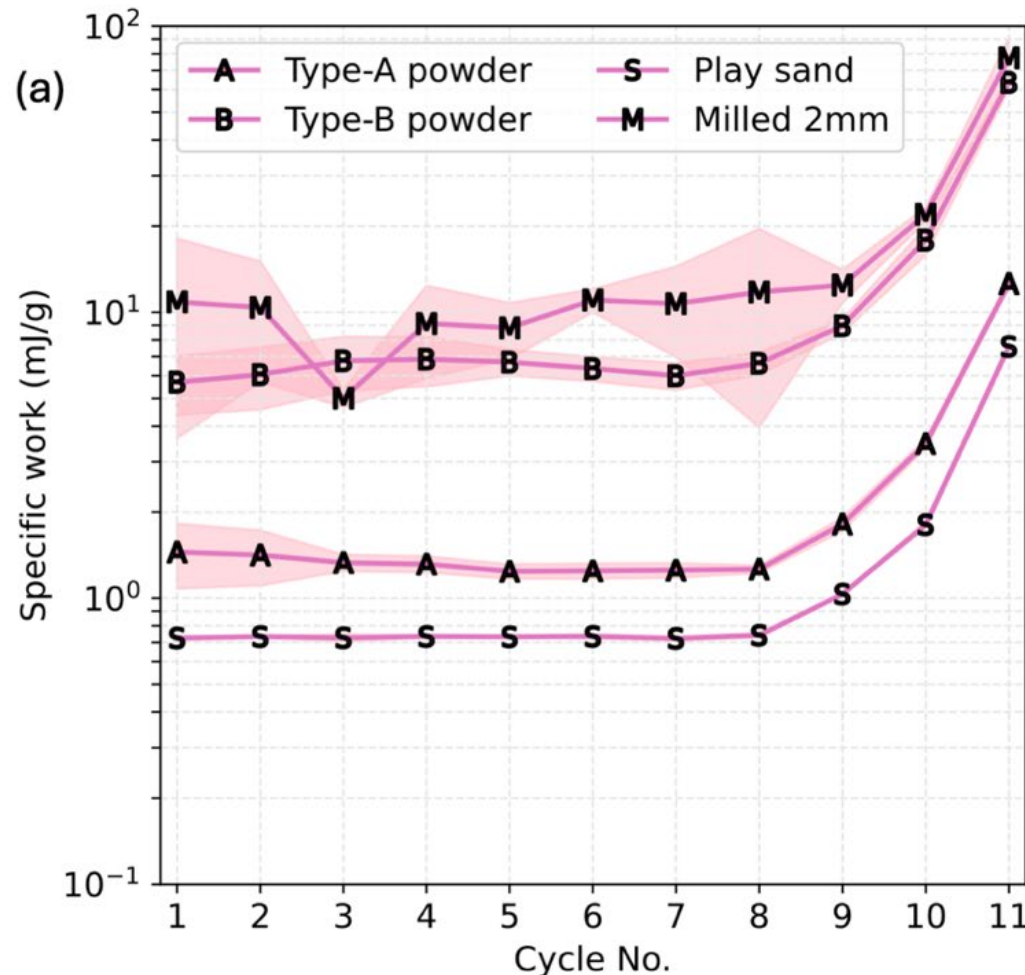
$$W = \int_0^h [M / (r \cdot \tan \alpha) + F_N] dh$$

M = torque; F_N = normal force; r = impeller radius; α = helix angle;
h = penetration depth

- Energy values are normalized by sample mass (specific work).



Flow Energy: Results



Key takeaway: Type-B powder requires ~5x more energy to mobilize than Type-A and trends toward compaction ($SI > 1$), signaling markedly lower mobility in mechanically driven feeding despite both being processed powders.

Conclusions

- **First-of-a-kind:** this is the first demonstration that solid biomass can be reliably fed into a commercial-scale entrained-flow gasifier via UDP feeding.
- **Density matters:** at similar particle size, the denser powder (Type A) needed ~5x less energy to mobilize and stayed more stable under repeated shear than Type B.
- **Densification–Torrefaction–Pulverization steps are required not complimentary to each other.**

Future Works

- **Scale-up:** advance to the full 200-ton pilot campaign with GTI Energy to prove continuous R-GAS™ operation on biomass.
- **Process economics:** improve torrefaction and pulverization energy efficiency and cost to strengthen commercial techno-economics.
- **End-to-end integration:** connect upstream feedstock processing with downstream syngas-to-fuels/chemicals conversion for full biorefinery demonstration.

Acknowledgements

- This research is supported by the U.S. Department of Energy (DOE), Office of Critical Minerals and Energy Innovation (CMEI), Alternative Fuels and Feedstocks Office (AFFO), under DOE Idaho Operations Office with Contract No. DE-AC07-05ID14517.

Thank You!



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