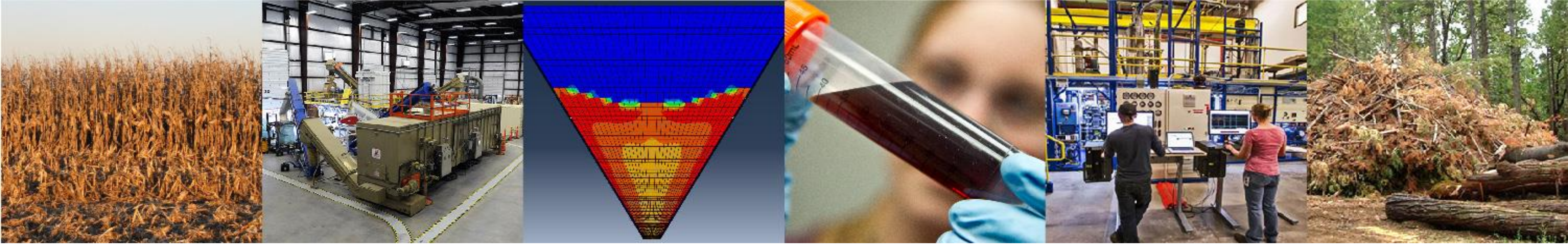

Pilot plant reliability metrics for grinding and fast pyrolysis of woody residues

Daniel Carpenter, Vicki Thompson, Katie Gaston, Neal Yancey

October 8th, 2019

tcbiomassplus 2019

fcic FEEDSTOCK-CONVERSION INTERFACE CONSORTIUM

Outline

- Background & Motivation
- Feedstock-Conversion Interface Consortium (FCIC)
- Objectives of Pilot-Scale Tests
- Materials and Methods
- Experimental Results
- Summary and Conclusions

It Takes a Village

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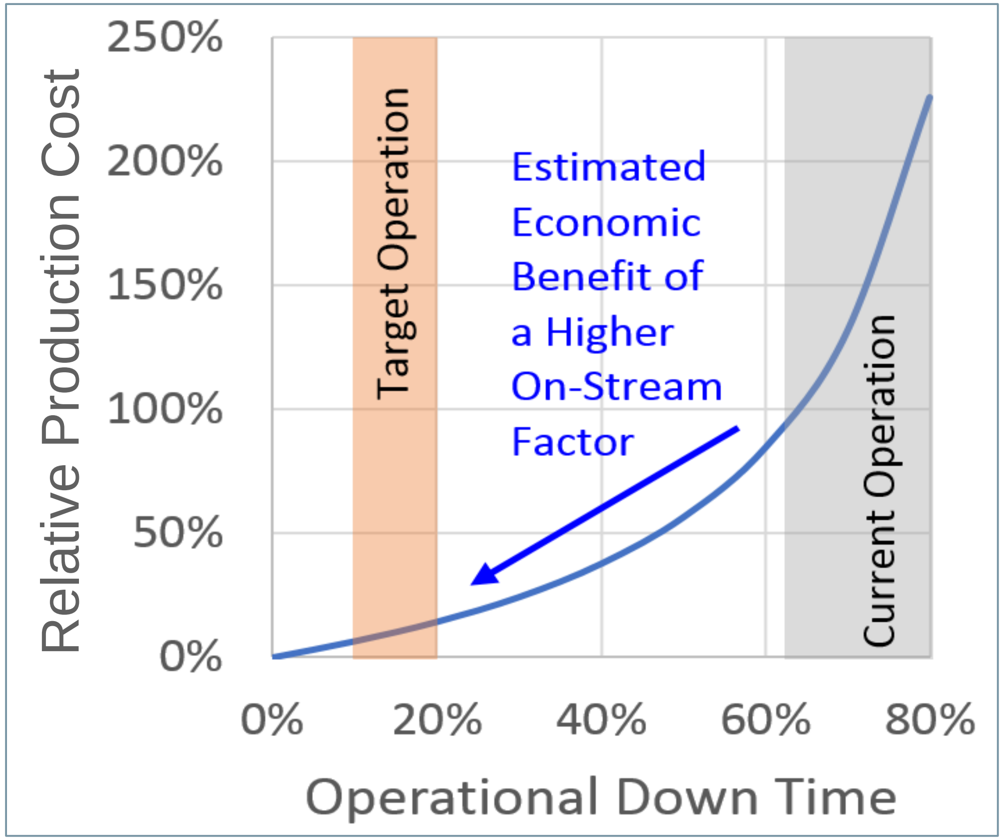
Background

- **Problem:** Most pioneer biorefineries have failed
- **Why?** (Mostly) moving biomass is hard! 'Real-world' feedstocks are not well understood
- **Feedstock Conversion Interface Consortium (FCIC):**
  - 9 National Laboratories
  - Goal: Understand how biomass variability (chemical, physical, mechanical) impacts critical unit ops
- **Outcomes:**
  - **Fundamentals** of feedstock-process interactions
  - **Scaling** relations
  - Valuation of **intermediates**
  - Improved ***Operational Reliability***



*Adapted from biomass-to-gasoline conceptual design**

**NREL/TP-5100-62402, PNNL-23822, 1-189*

Experimental Approach

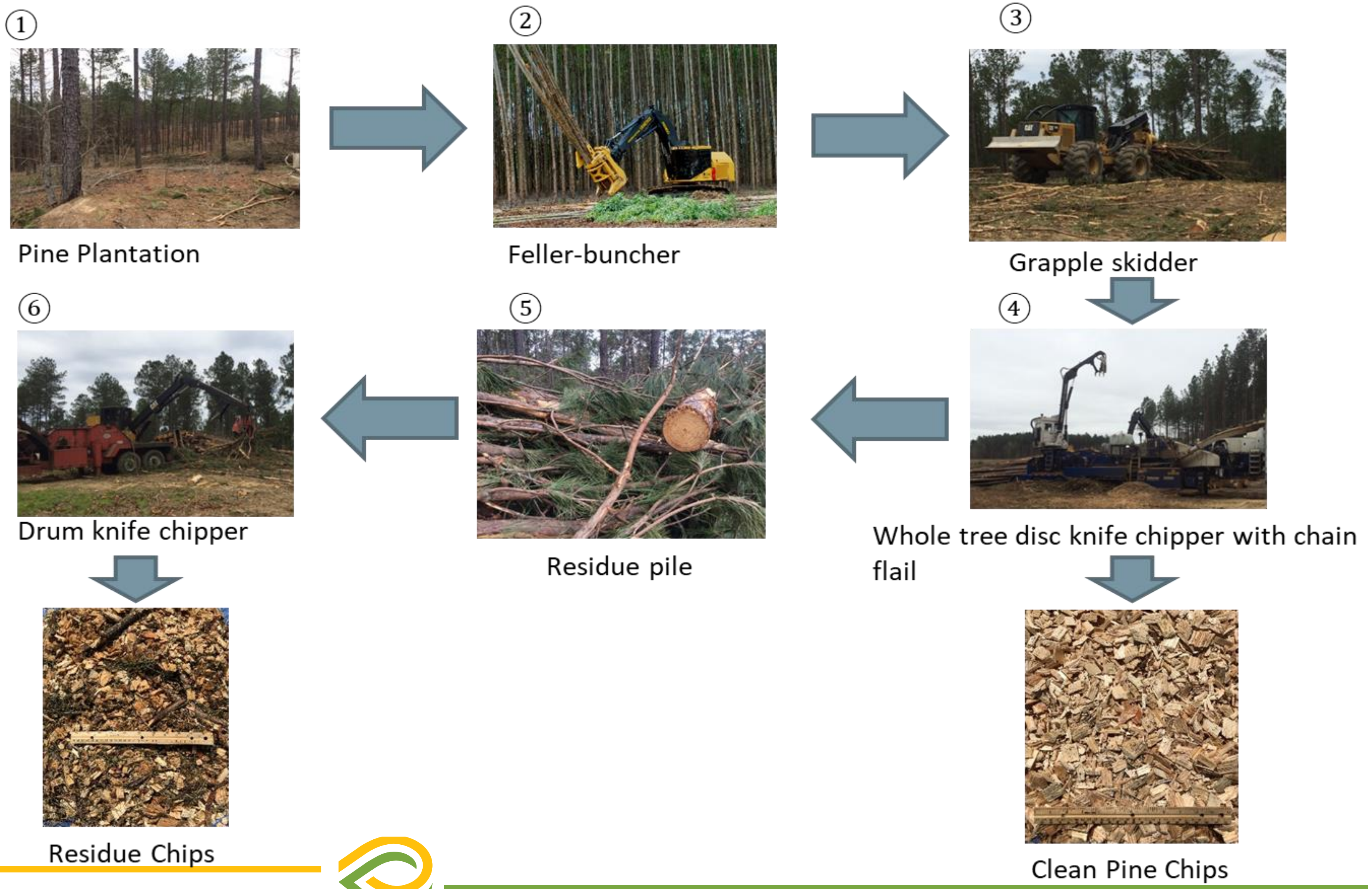
- How do we measure process reliability (or productivity)?
- What feedstock attributes can we control?
- 2 x 2 matrix
- Collect data for:
  - Process variables
  - Material characterization
  - Observational

  (interventions, downtime, etc.)

Ash Content ↑	Moisture *at grinder* →	
	HALM 10% 3-4%	**HAHM** 30% 3-4%
	LALM 10% <1%	**LAHM** 30% <1%

Forest Residue Sourcing

- Commercially harvested
- Debarked loblolly pine (low ash)
- Loblolly pine tops/limbs (high ash residues)
- Chipped to 2”
- Moisture at harvest: ~50%
- Age at harvest: 11-25 yr



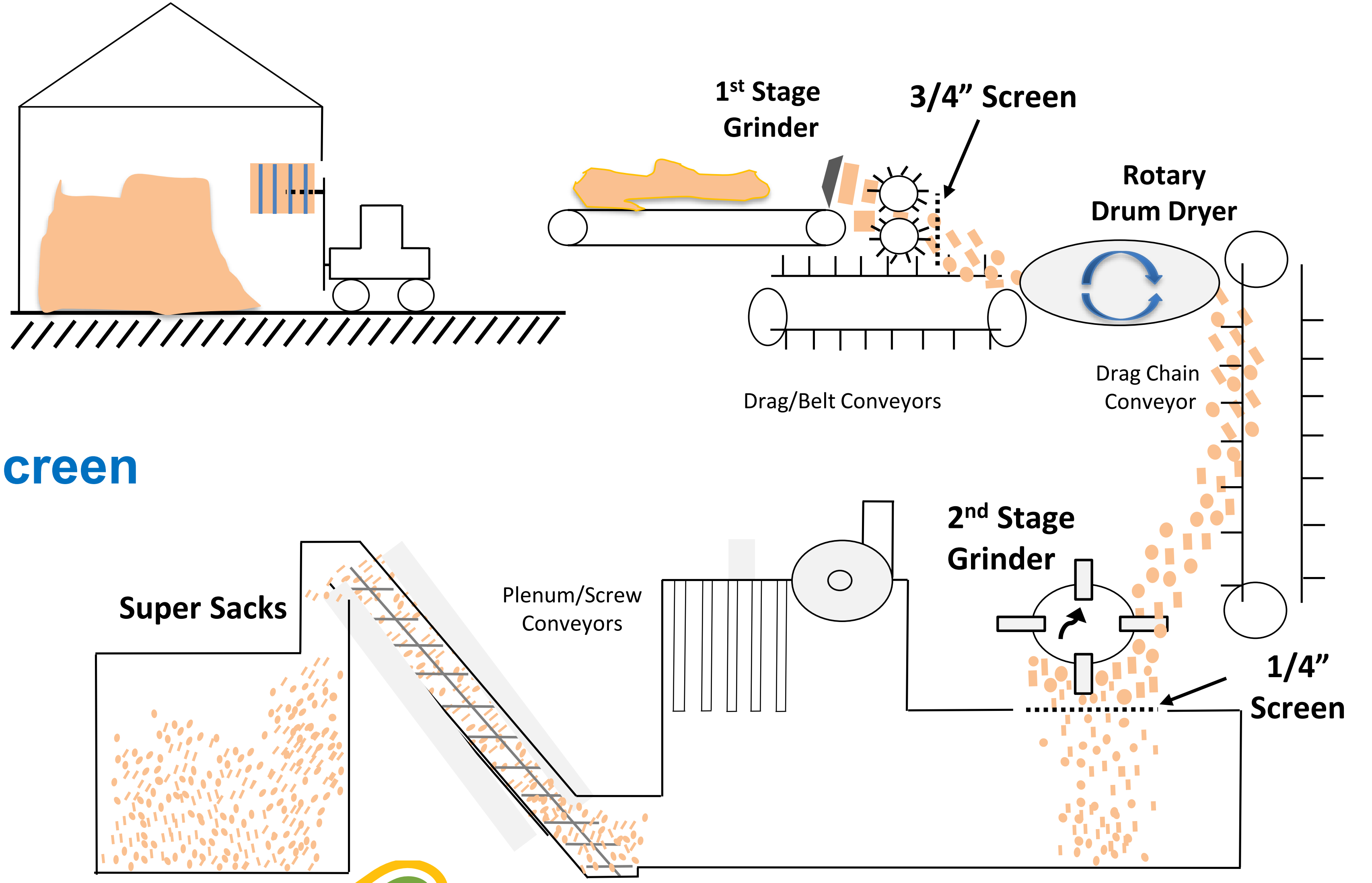
Preprocessing (INL BFNUF)

Biomass Feedstock National User Facility

Preprocessing Process Flow

Throughput: 5 ton/h

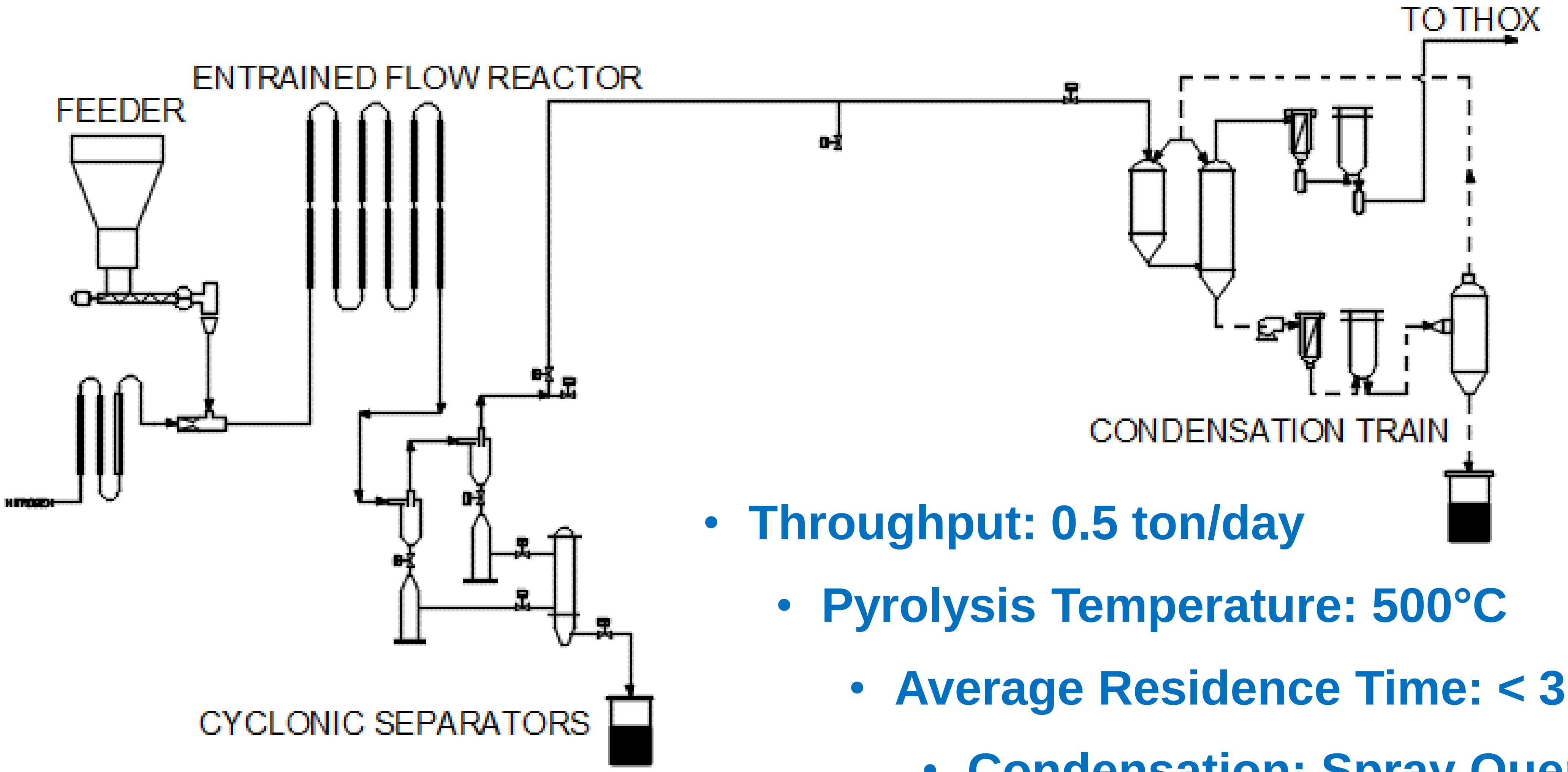
1. Grind to ¾”
2. Dry to 10% or 30%
3. Hammer mill to ¼” screen
4. Dry all to <10%



Fast Pyrolysis (NREL TCPDU)

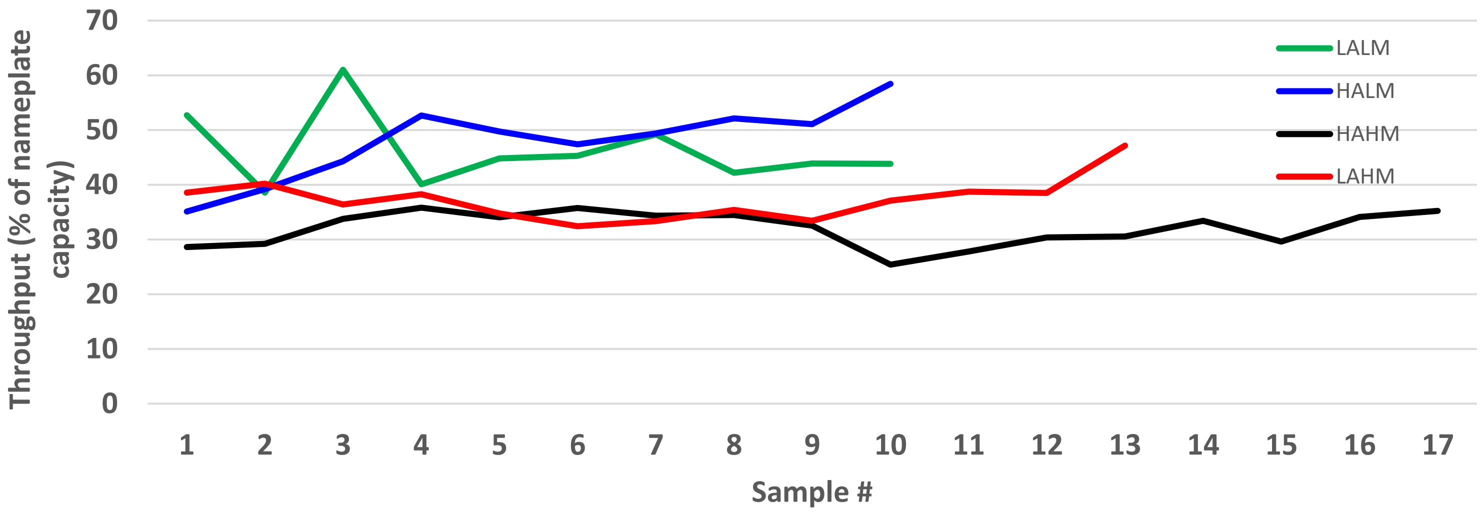
Thermal & Catalytic Process Development Unit

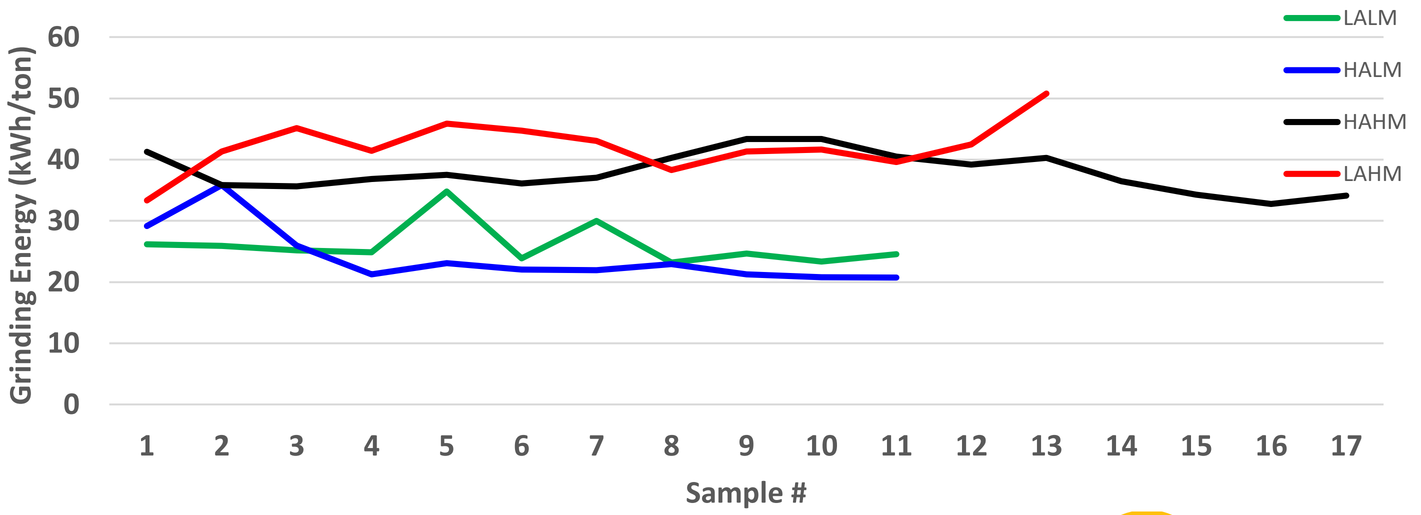
Fast Pyrolysis Process Flow

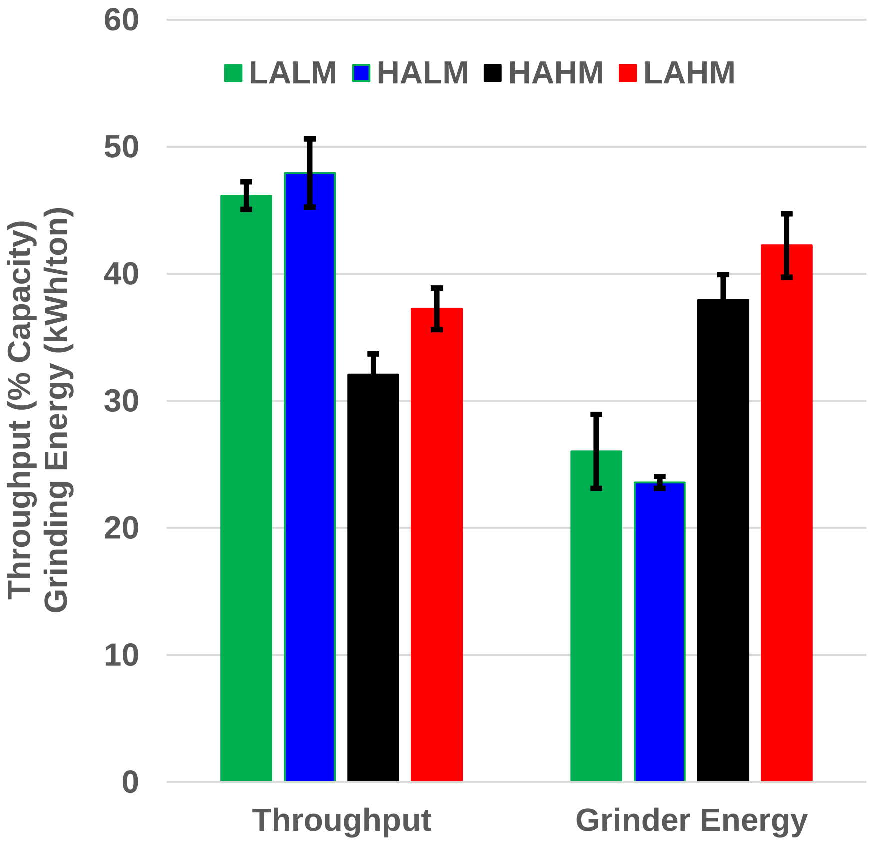


- Throughput: 0.5 ton/day
- Pyrolysis Temperature: 500°C
- Average Residence Time: < 3 s
- Condensation: Spray Quench

Grinder Throughput & Energy Use



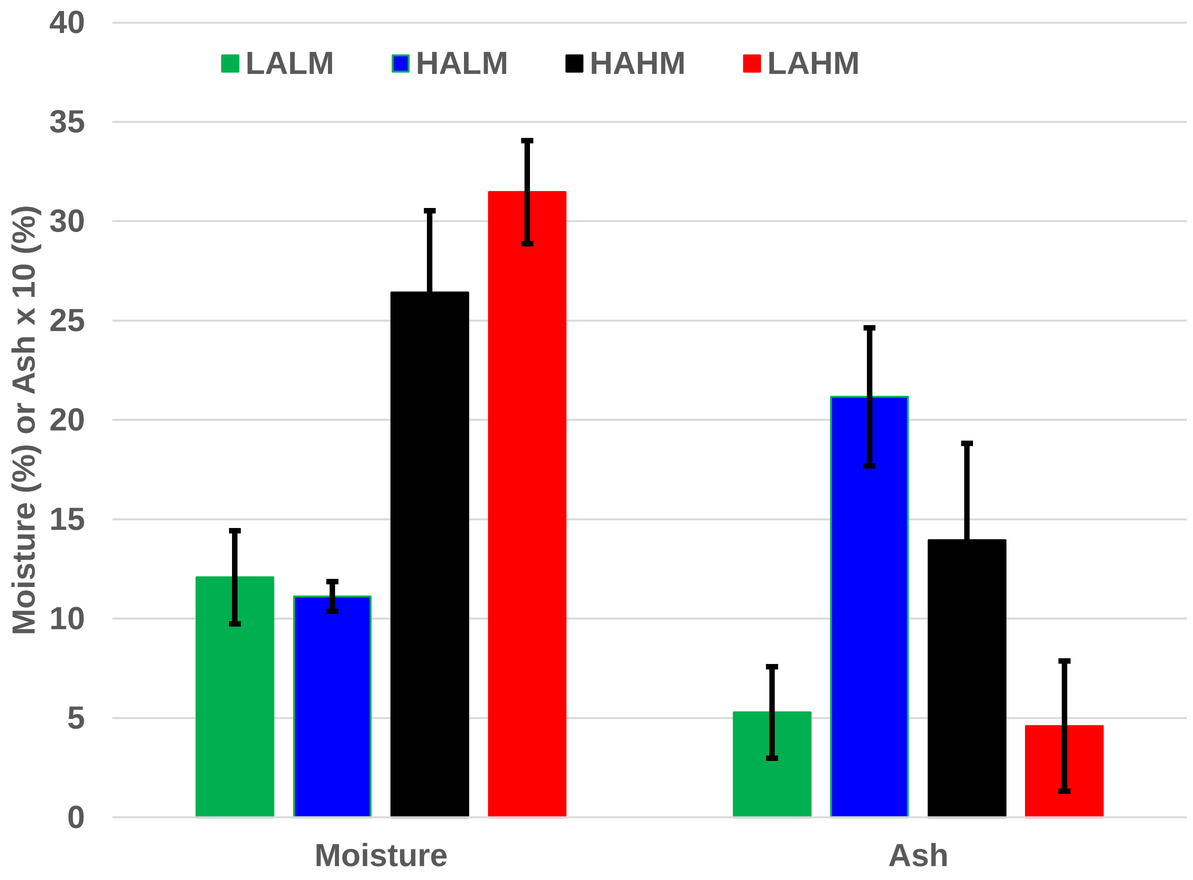


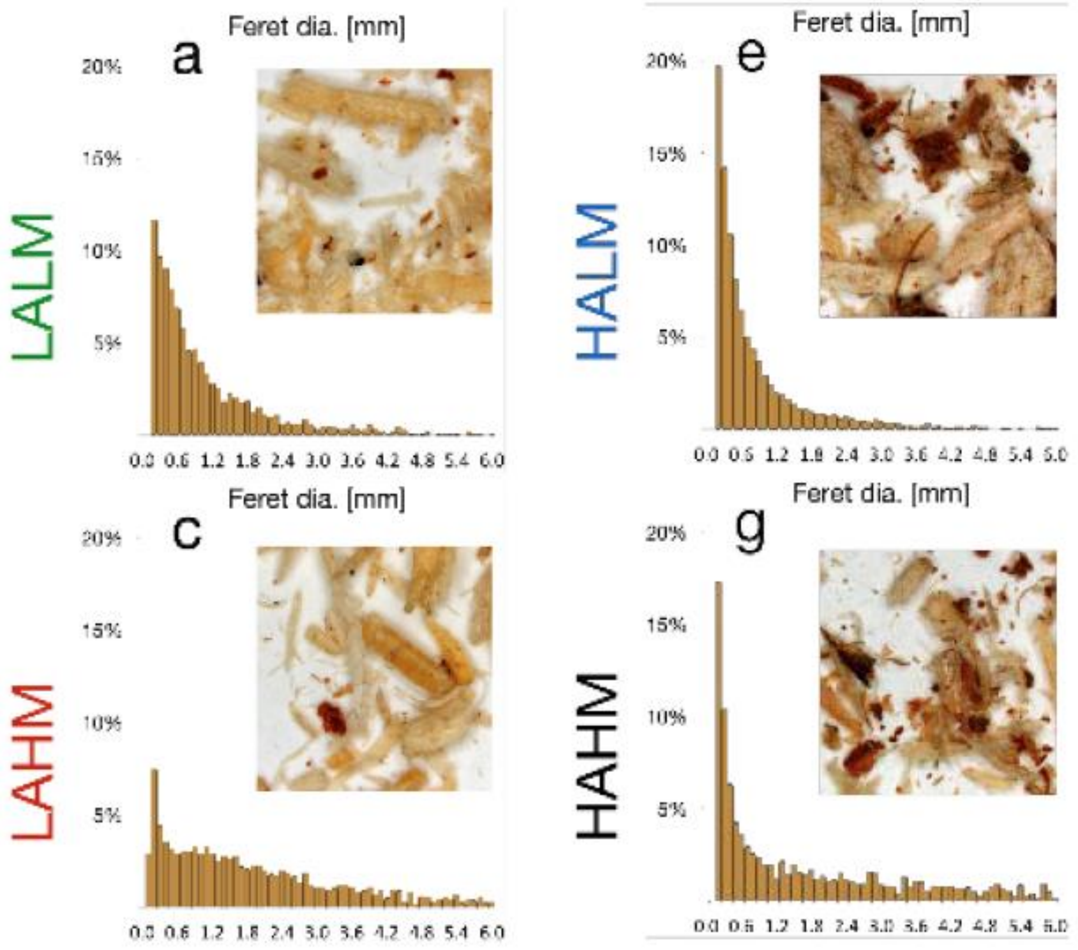


*2x grinder overloads w/ low ash

*6x grinder overloads w/ high moisture

Feedstock Properties

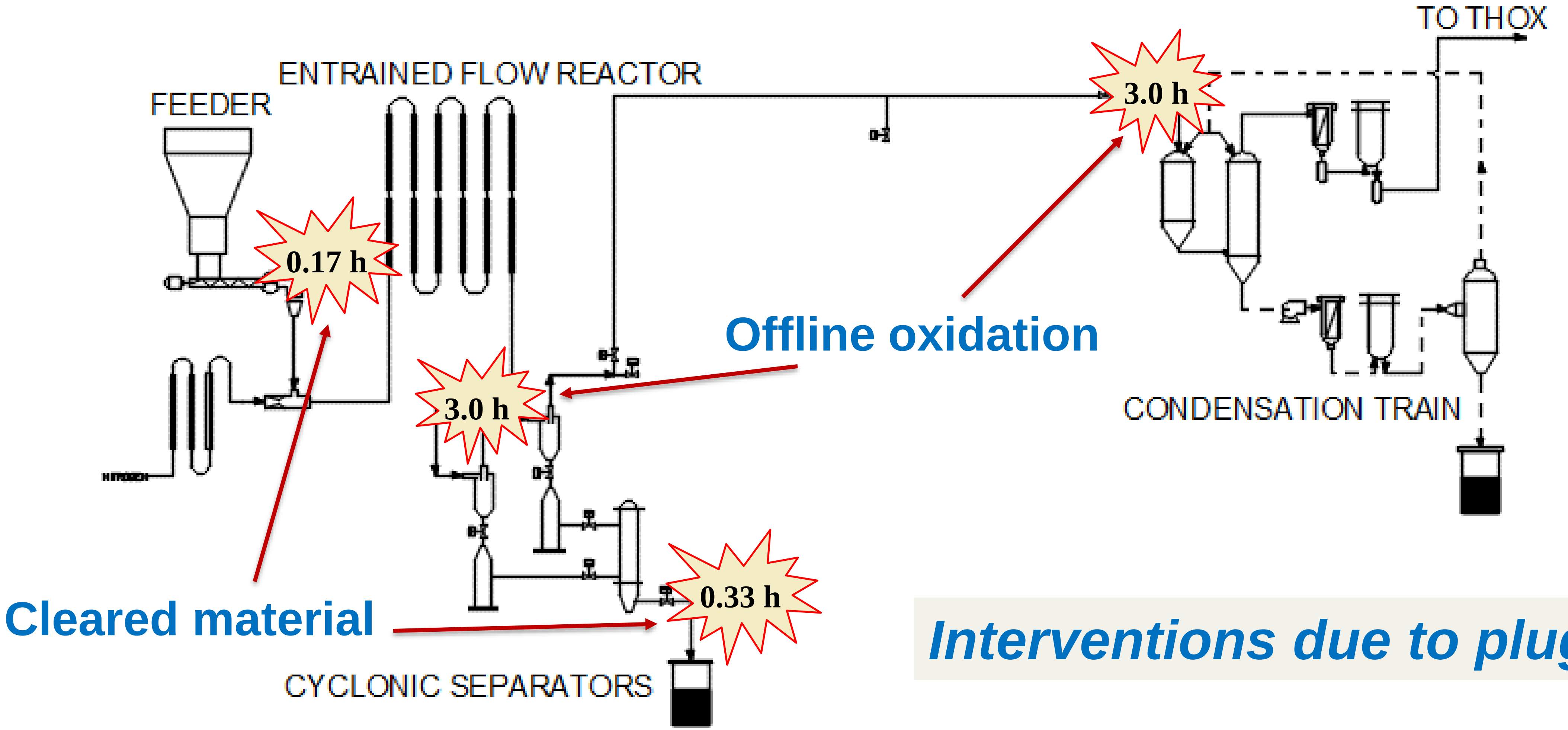




Particle size distributions

- Wood particles in high-ash samples appears smoothed
- High moisture samples ~20% larger mean particle size

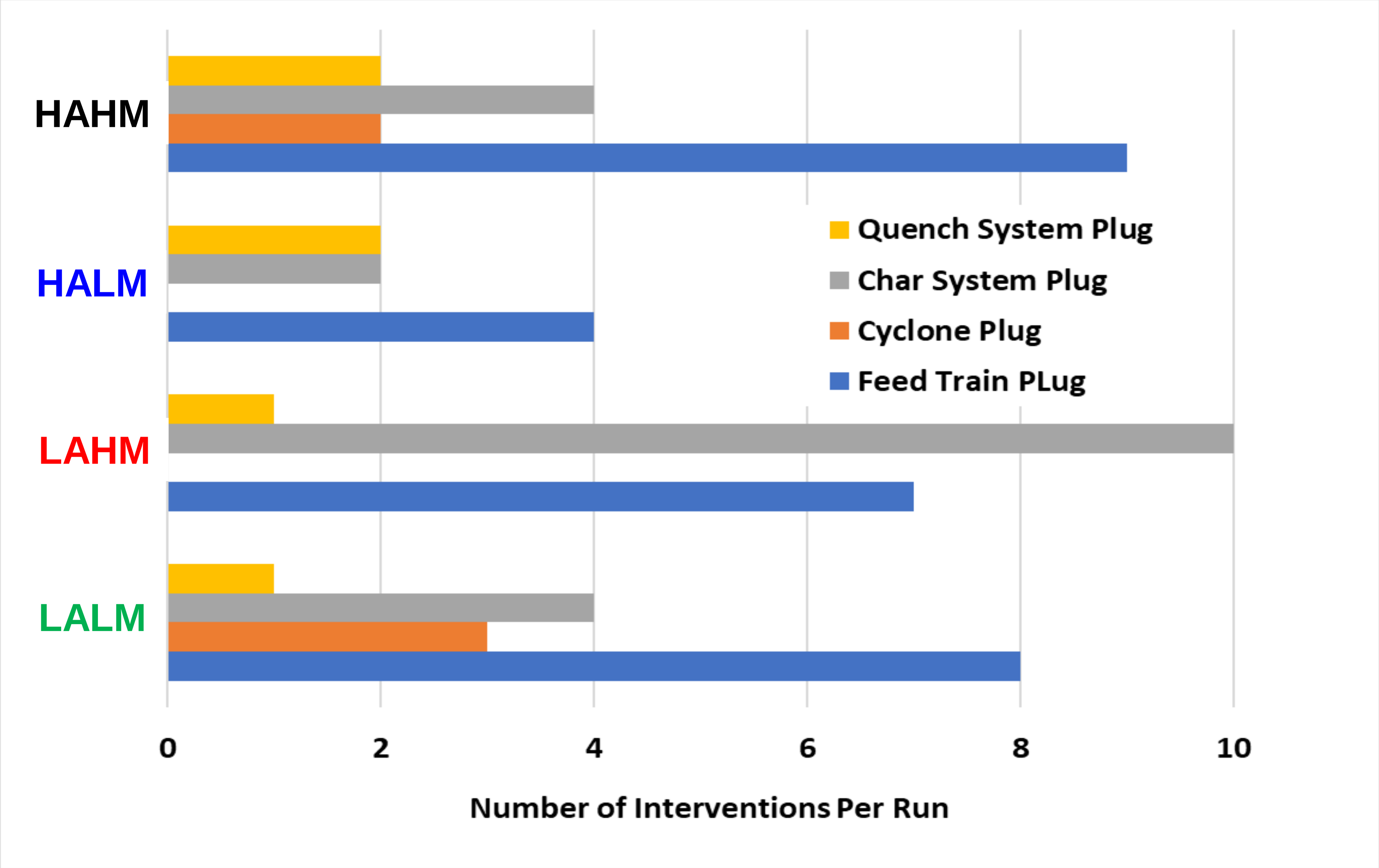
Pyrolysis Operations



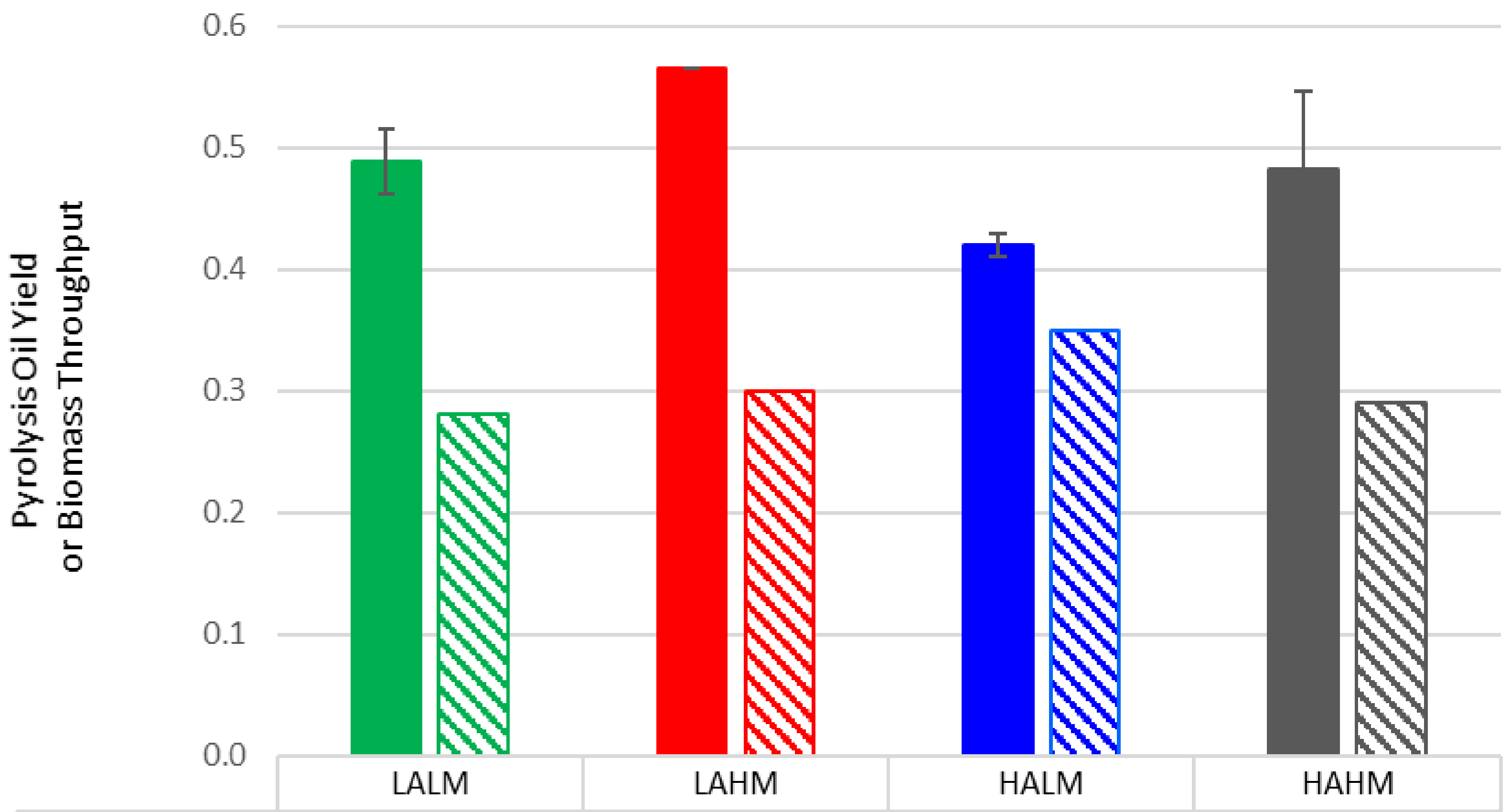
Interventions due to plugging

Operator Interventions

- Significant variation between feedstocks
- **High-Ash/Low-Moisture,** required fewest interventions
- On-stream factors:
  - ✓ **LALM – 0.57**
  - ✓ **HALM – 0.71**
  - ✓ **HAHM – 0.58**
  - ✓ **LAHM – 0.59**



Pyrolysis Throughput & Yield

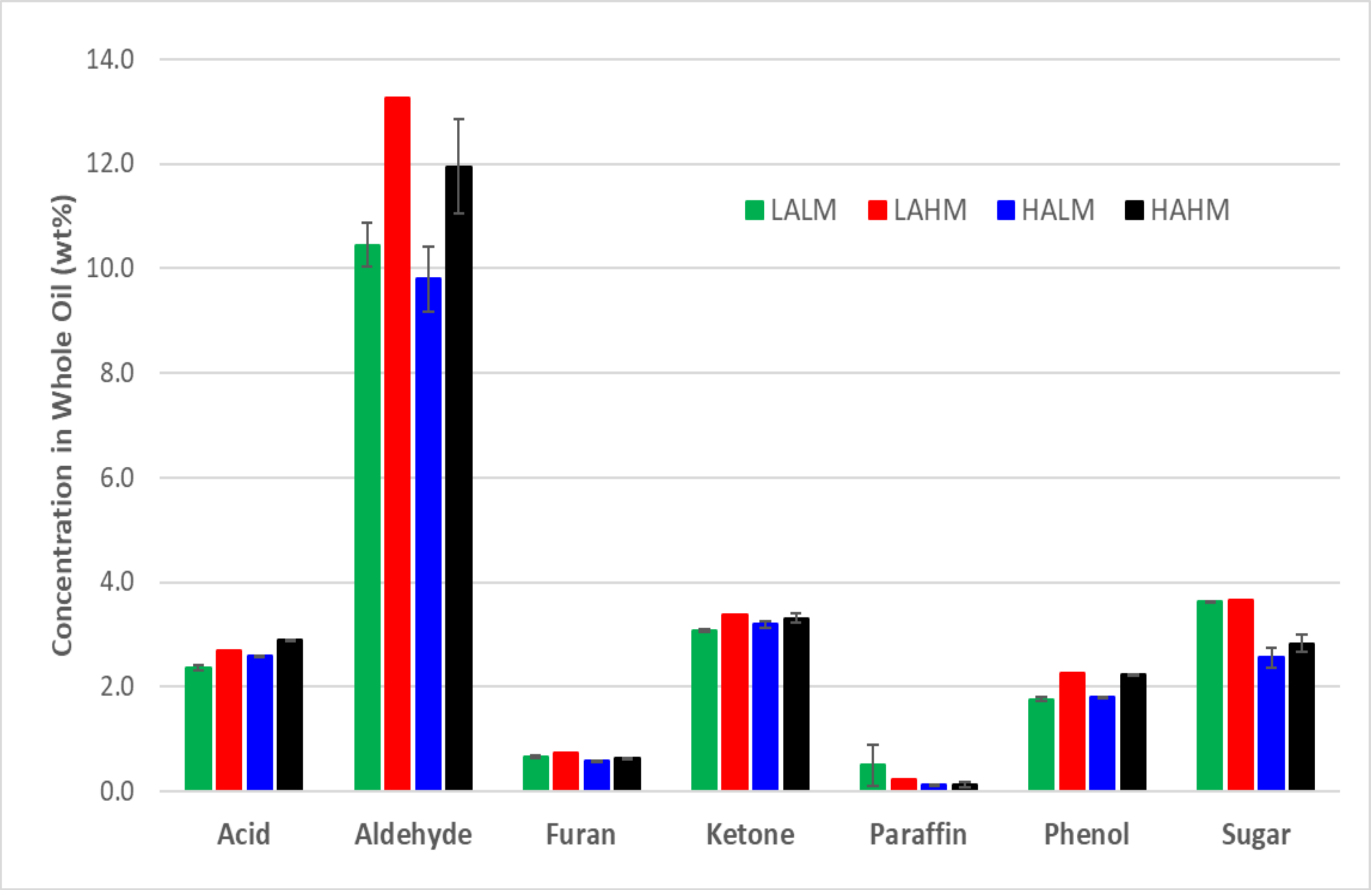


	LALM	LAHM	HALM	HAHM
Yield (d.a.f.)	48.9%	56.5%	42.0%	48.3%
Throughput (tpd)	0.28	0.30	0.35	0.29

- Mass Balances: 83-89%
- **High-ash** produced:
  - 3-4% more water
  - More char
  - More light gases

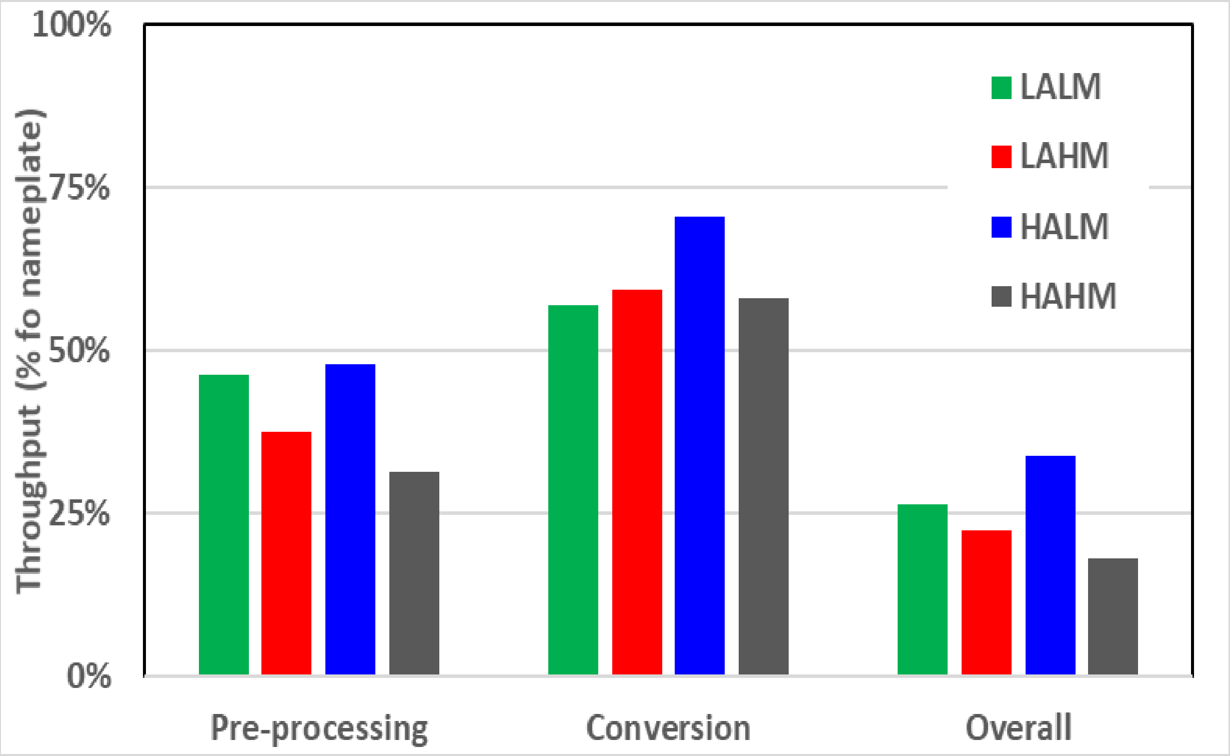
Pyrolysis Oil Quality

- **High-moisture** feedstocks → **Higher aldehydes** in oil
- **High-ash** feedstocks → **Lower sugar** in oil (consistent with alkali metal-catalyzed reactions)

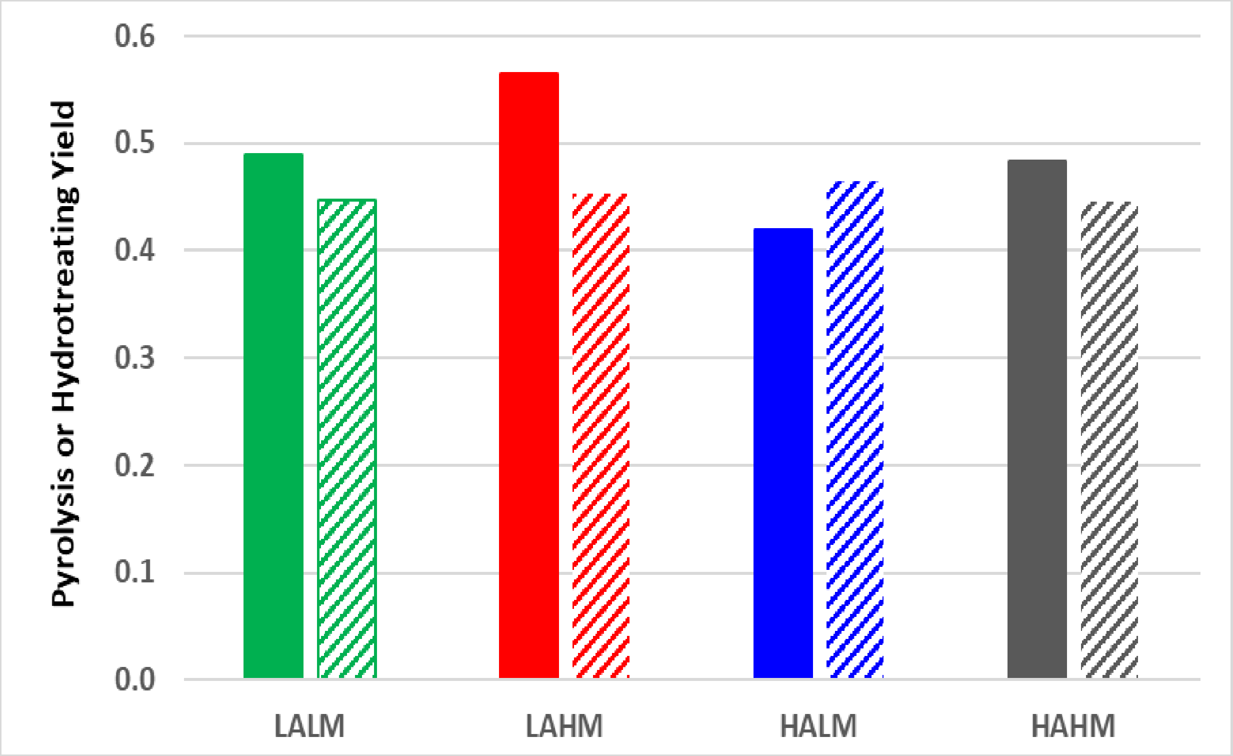


GC-MS Analysis of Pyrolysis Oils

Combined System Performance

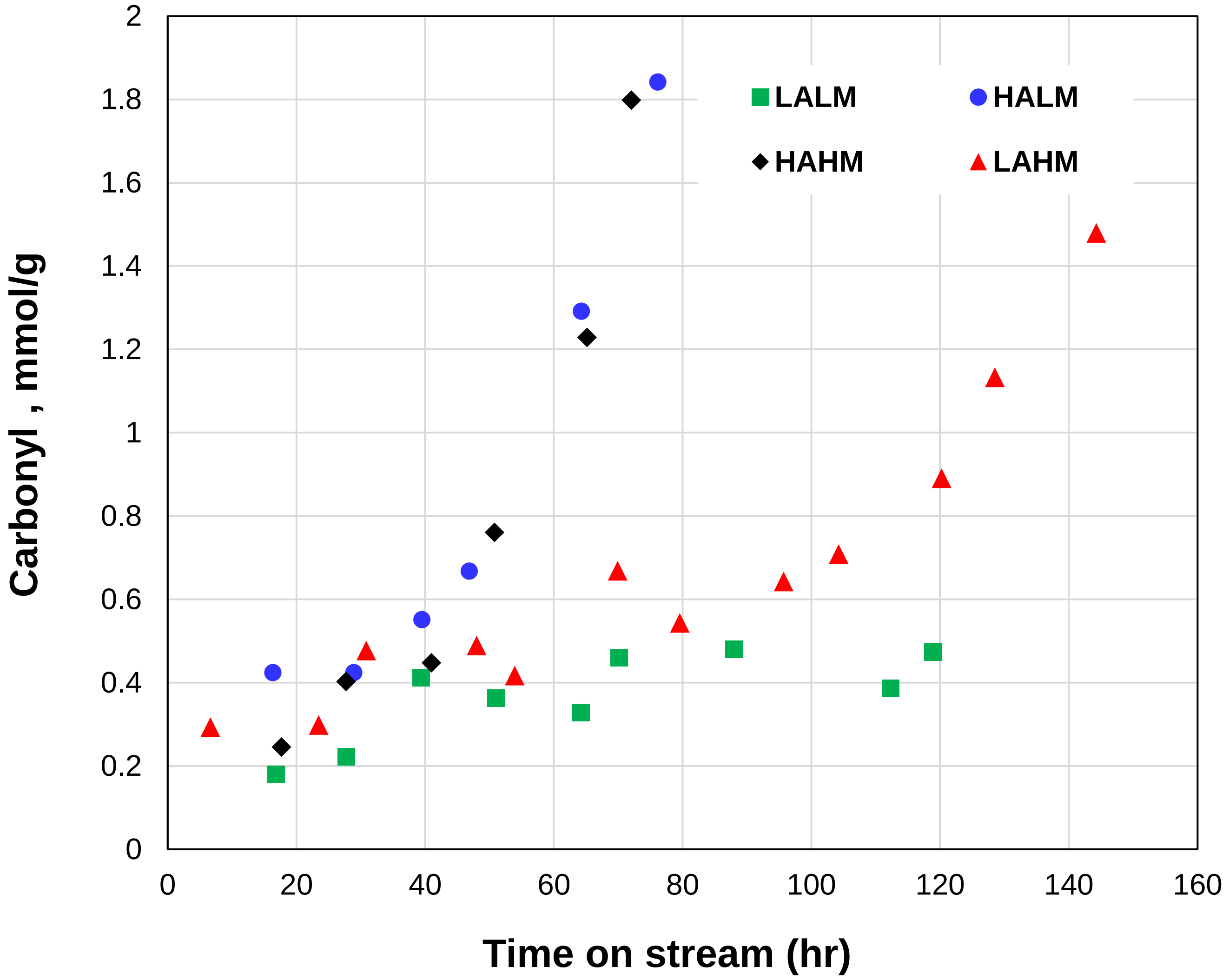


System throughput



- Hydrotreating yields are similar
- H_2 consumption varies

‘Hydrotreatability’ of the oil



- Catalyst life varies (**carbonyl** vs. time)
- **High-ash** oils have **higher sulfur**
- But…**low-ash** feedstocks have *more* sulfur…

Summary & Conclusions

- **High-Ash/Low Moisture** feedstock had highest throughput
- **Preprocessing** throughput (INL BFNUF) = 31-48% of nameplate capacity (5 T/hr)
- **Conversion** throughput (NREL TCPDU) = 57-72% of nameplate capacity (20 kg/hr)
- **Overall** throughput (preprocessing x conversion to oil) was 18-35% of nameplate capacity
- **Yield** to pyrolysis oil varied between 46-53% ($g_{daf\ oil}/g_{biomass}$)
- Combined performance/efficiency of the entire process must be considered

Acknowledgements

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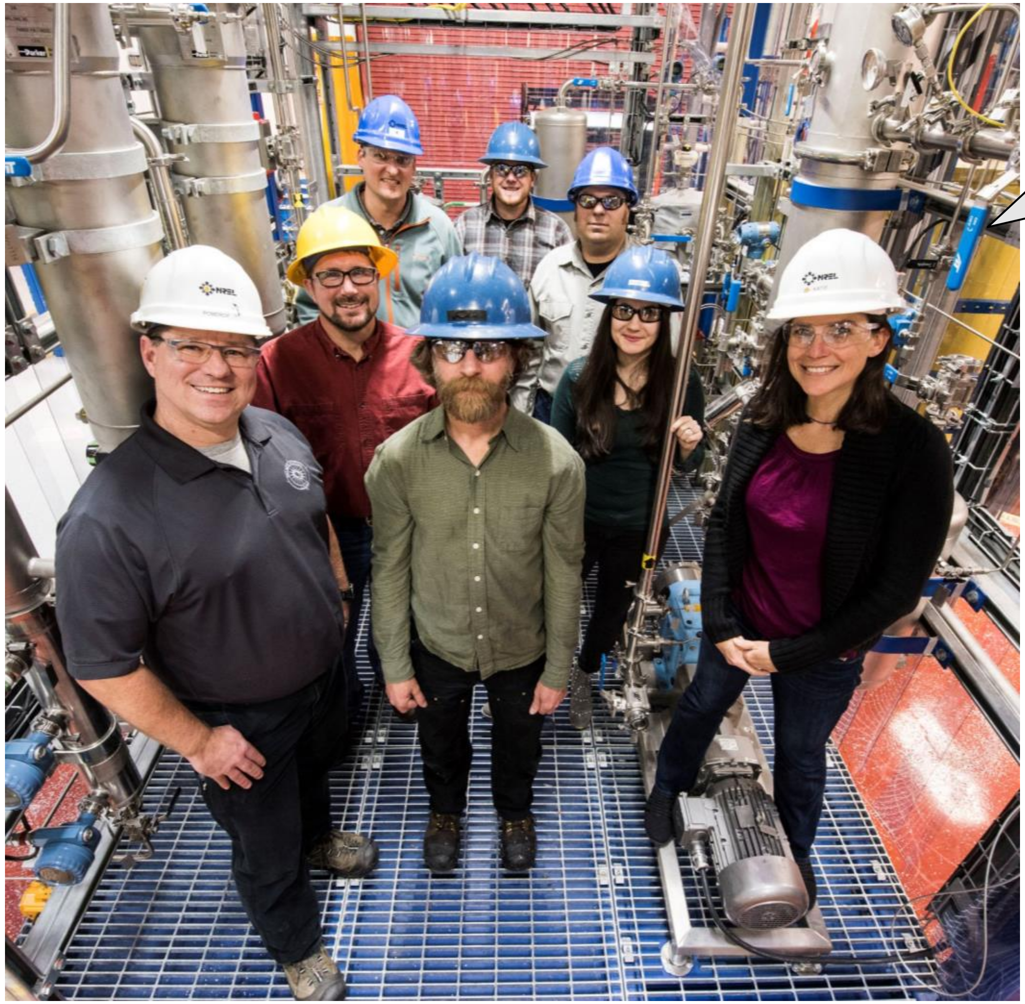


We have oil!

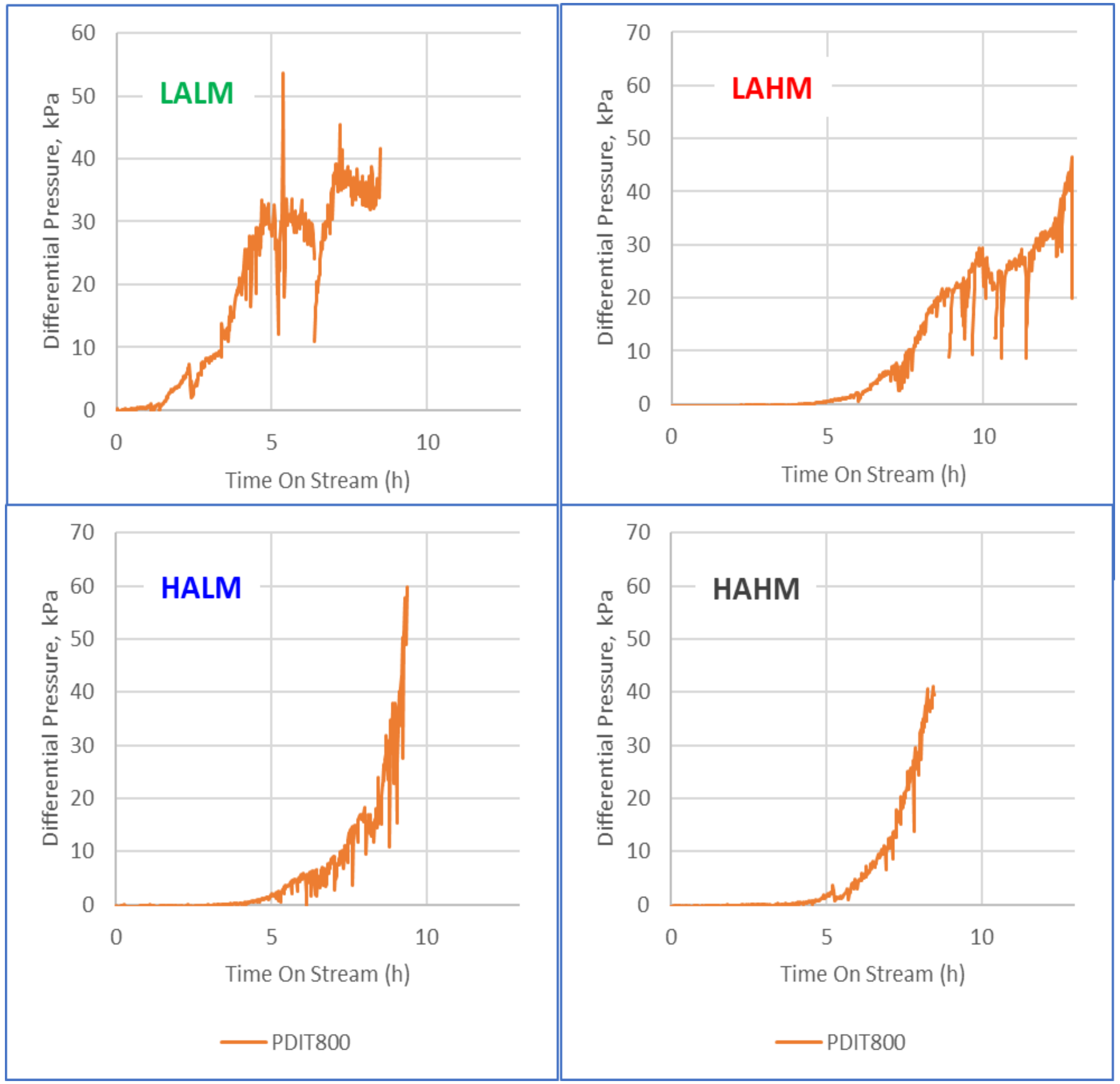
Supplemental Material

Feedstock Source and Preprocessing

	Clean Pine	Forest Residues
Sample:	Clean Loblolly Pine	Loblolly Pine Residues
Harvest Site:	Screven, GA; 3/27/18	Edgefield County, SC; 3/26/18
Moisture Content:	49.3% at harvest	50.9% at harvest
Anatomical Fraction:	Chips of de-barked stem / bole, 11-25 years of age	Loblolly in-woods tops, ~7-in. dib at large end, 11-25 years of age
Harvest Equipment:	TIGERCAT 724G Feller buncher, TIGERCAT 630E grapple skidder, Peterson Pacific 5000H Disc Chipper with flail chains	CAT 563D Feller buncher, CAT 535D grapple skidder, CAT 559C knuckleboom loader, MORBARK 40/36 drum knife chipper
Harvest Operations:	Debarked, chipped, 2-in. nominal, ~23 tons (wet) loaded directly to trailer	Tops removed and placed in a pile, chipped 2-in. nominal, ~22 tons (wet) loaded directly into trailer
Screening:	NO	NO




Plugging at Scrubber



- Graphs are differential pressure across scrubber inlet
- Low-ash and high-ash feedstocks have different “plugging profiles”

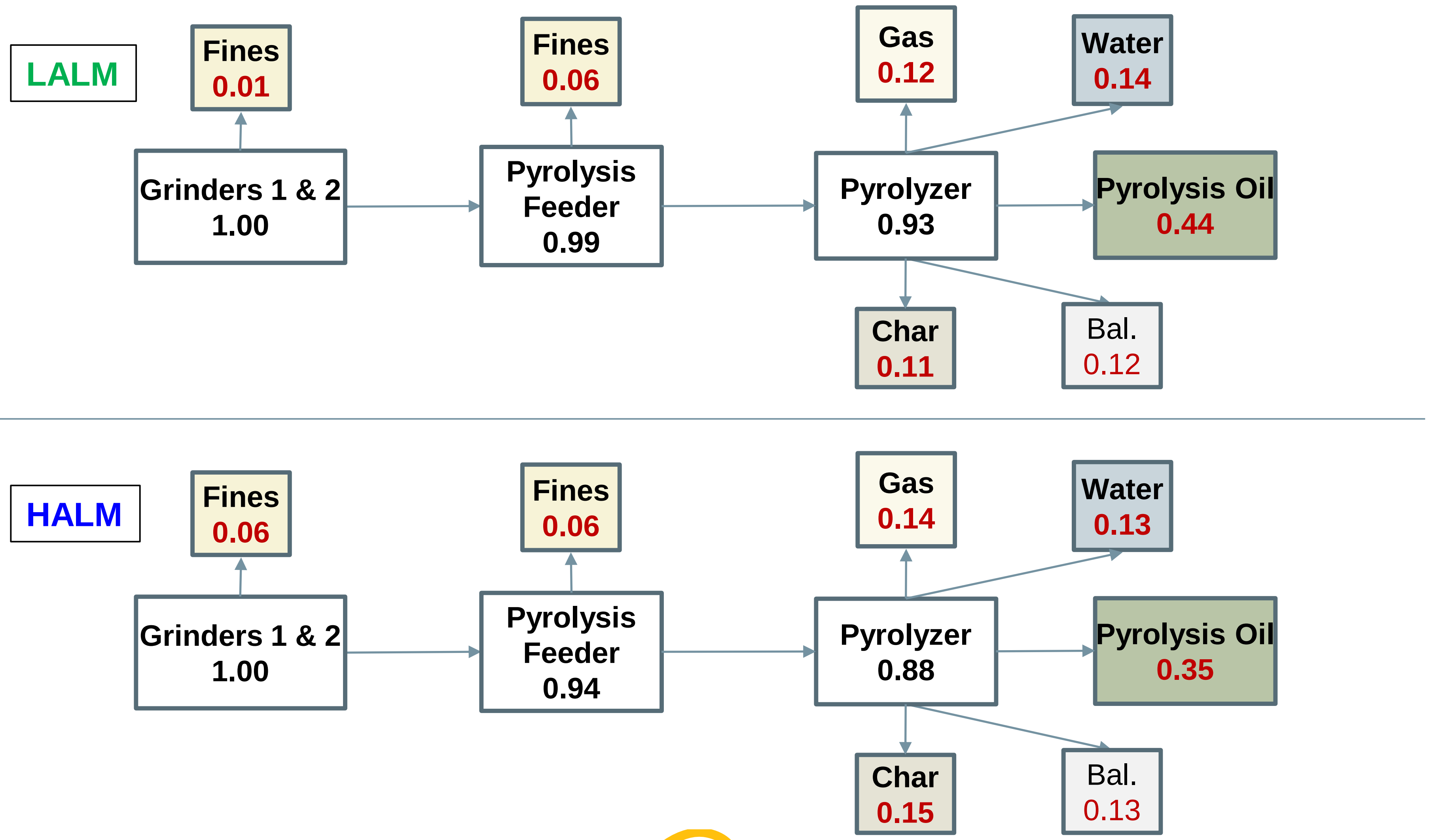
- Suggests different condensation mechanism or composition of deposits

Feedstock Analysis

Properties	LALM	LAHM	HALM	HAHM
Proximate analysis (wt-% dry, ash free) unless otherwise noted				
Moisture (%)	9.7	8.13	8.7	8.08
Ash (wt% dry)	0.52	0.49	2.52	1.55
Volatile Matter	84.6	84.66	80.57	81.24
Fixed Carbon	14.9	14.85	16.91	17.21
Ultimate analysis (wt-% dry, ash free)				
C	51.0	51.29	50.57	50.90
H	6.03	6.12	5.79	5.75
O (by diff.)	42.3	41.96	41.01	41.61
N	0.05	0.01	0.16	0.13
S	0.14	0.14	0.06	0.06
Compositional analysis (wt-%, dry basis)				
Extractives	3.14	3.15	4.32	4.65
Glucan	40.47	40.25	35.72	34.98
Xylan	6.51	6.43	7.15	6.90
Galactan	2.18	2.39	2.69	3.16
Arabinan	1.93	1.55	1.96	1.35
Mannan	12.24	11.63	10.66	10.51
Lignin	32.84	33.74	36.00	36.25
Particle Size Distribution (mm)				
Geometric Mean	1.16	1.26	1.14	1.34
D10	0.3	0.36	0.25	0.38
D50	0.94	1.01	0.93	1.06
D90	1.95	2.05	2.53	2.49

Feedstock	LALM	LAHM	HALM	HAHM
Product Yields (wt-% of biomass fed, wet basis)				
Total Liquid	62.3	69.6	54.1	60.2
Char	11.2	13.8	14.7	14.1
Gas	12.6	12.8	14.9	13.2
Mass balance	86.1	88.2	83.3	89.1
FP Oil Analysis (wt-% as received)				
Ash	<0.05	<0.05	<0.05	<0.05
C	43.1	44.0	41.1	42.2
H	7.4	7.5	7.5	7.5
N	0.1	0.1	0.2	0.2
O (by diff.)	49.5	48.5	51.3	50.1
S	—	0.01	0.02	0.02
Water	23.5	20.5	26.4	24.5
Carbonyl (mol/kg)	5.78	6.54	5.51	5.78
TAN (mg KOH/g)	68.3	67.9	66.1	67.3
Viscosity (cp, 40 °C)	31.8	41.7	21.4	30.1
Density (g/cm³, 20 °C)	1.23	1.23	1.21	1.22

High-T Results (Mass Balances)



High-T Results (Mass Balances)