Rotary-shear Production of Flowable Uniform Feedstocks for Thermochemical Conversion to Renewable Diesel:

Technoeconomic Analysis and Experience with First Commercial Scale System

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Introduction

- Rotary Shears and Crumbles
  - Precision feedstocks for conversion to biofuels, biochemicals, and bioproducts
  - Biomass in, biomass out - making small particles
  - Veneer, wood chips, and herbaceous biomass

What is Crumbles® Feedstock?

- Physical properties are optimizeable for specific conversion processes
  - Length
  - Thickness
  - Moisture
  - Uniformity of size
  - Flowability
- Particle size converges on cutter thickness

Why Crumbles?

- Tolerant of high moisture
- Narrow particle size distribution
- Lower fines production
- Higher flowability - low aspect ratio
- Quieter than hammer mills and grinders
- Low / no dust production

Test Method

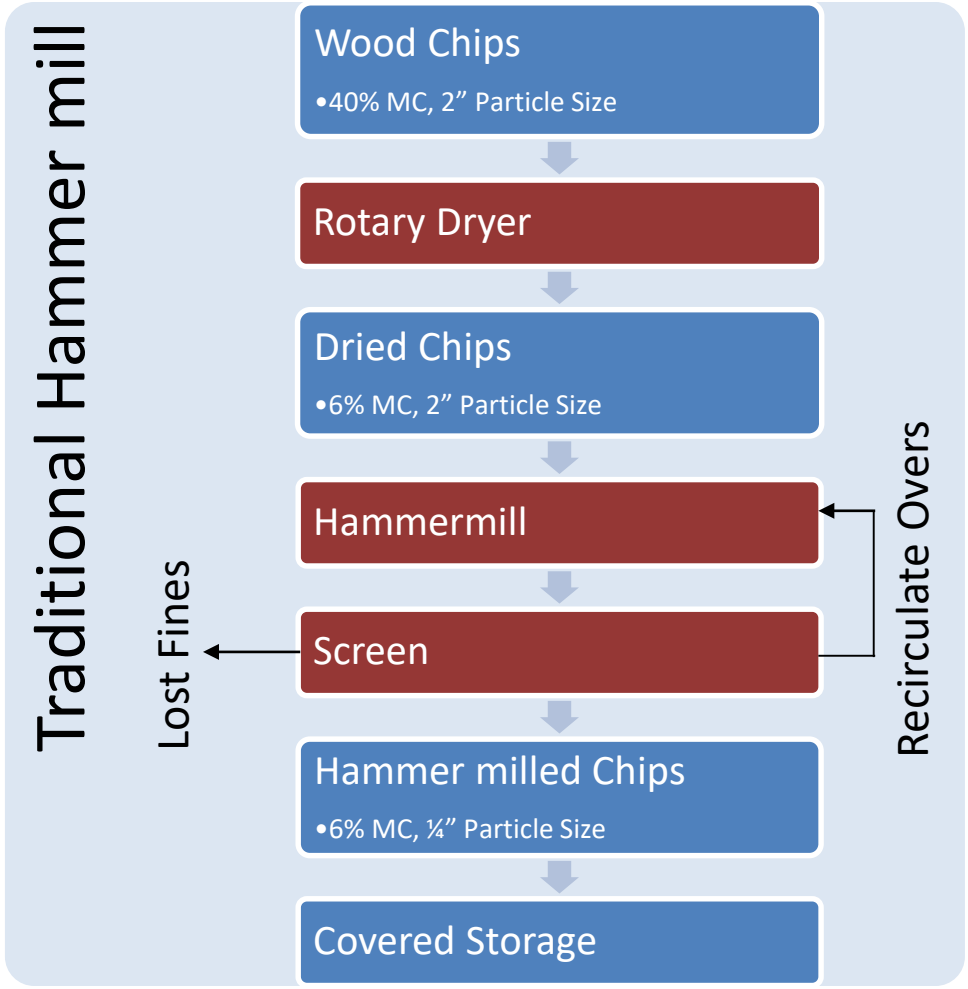
- Biomass Logistics Model (BLM)
  - Engineering performance databases of equipment
  - Spatially explicit labor cost datasets
  - Local tax and regulation data
  - Simulates flow of biomass through entire supply chain while tracking characteristic changes
    - MC, dry matter, ash, bulk density, etc

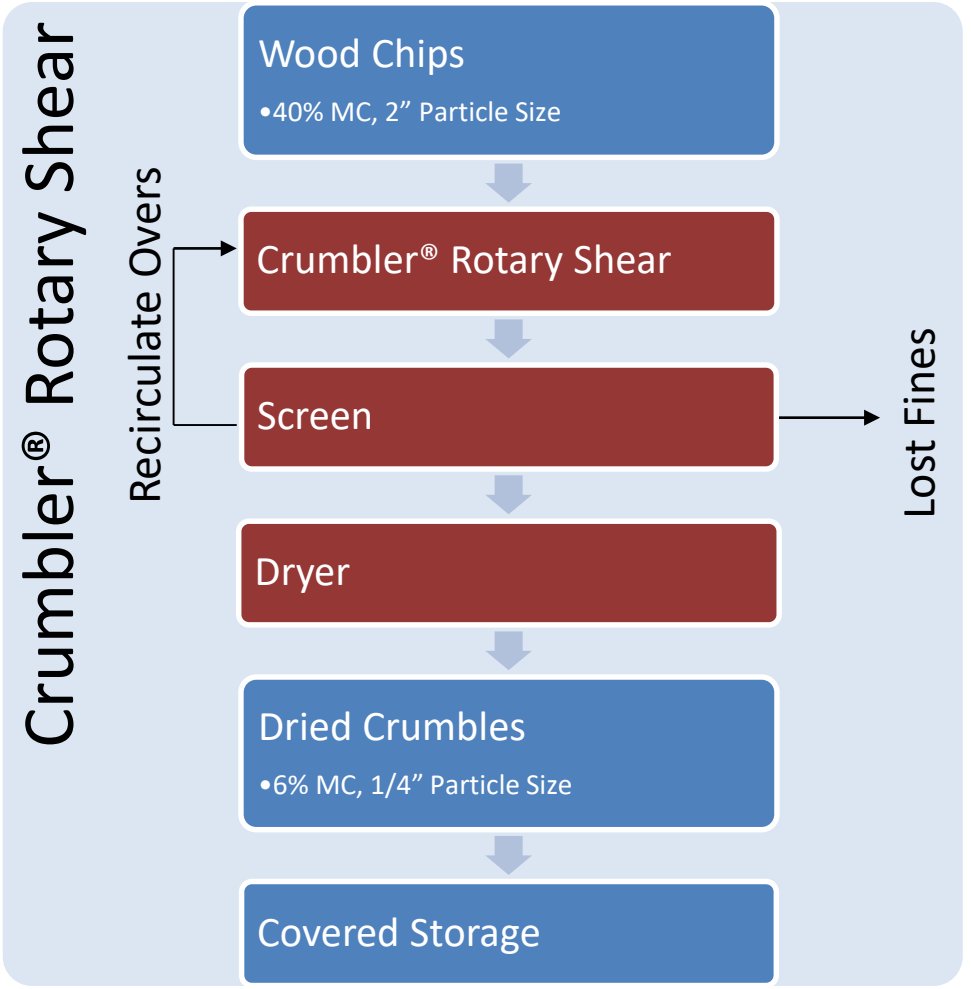
Modeling Scenarios

- Crumbler data collected at PPI, Rockwood, TN
- Hammermill and dryer data collected at INL's PDU
- Data scaled to 800,000 dry short tons per year reactor ready feedstock (95 short tons per hour)
- Each pathway starts with pulp quality hardwood chips
- Processed 16.5 tons through Crumbler
- 4 super sacks crumbles shipped to INL for drying
- 4 super sacks chips shipped to INL for hammer mill processing

Parameter	Cost
Wood Chips	$37.00 / dry ton
Electricity	$0.071 / kWh
Natural Gas	$5.39 / MMBtu
Off-Road Diesel Cost	$3.29 / gal
Interest Rate	8%

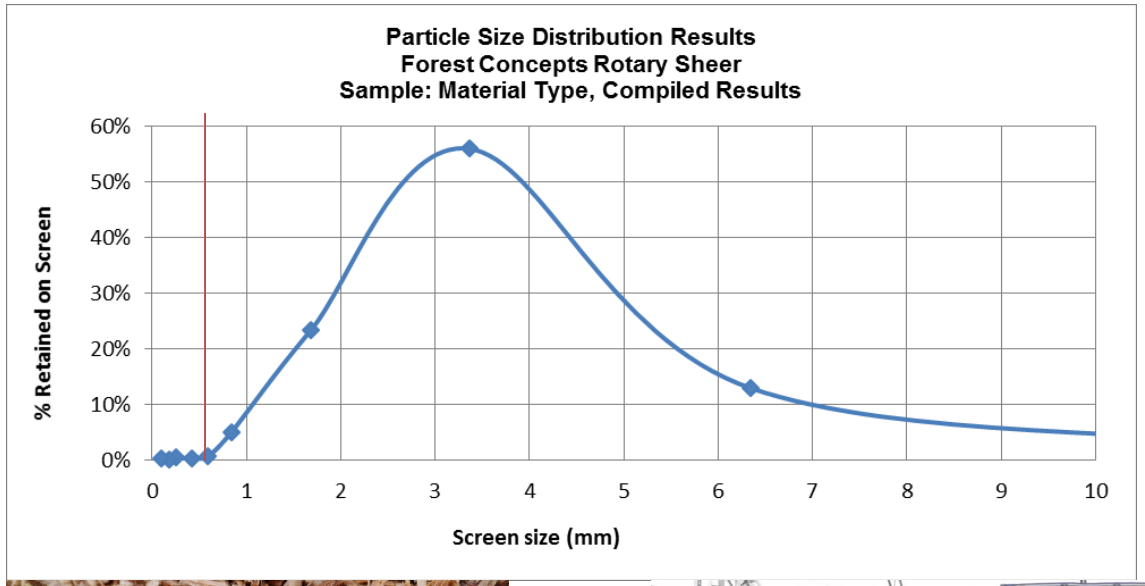
Modeling Scenarios - Pathways

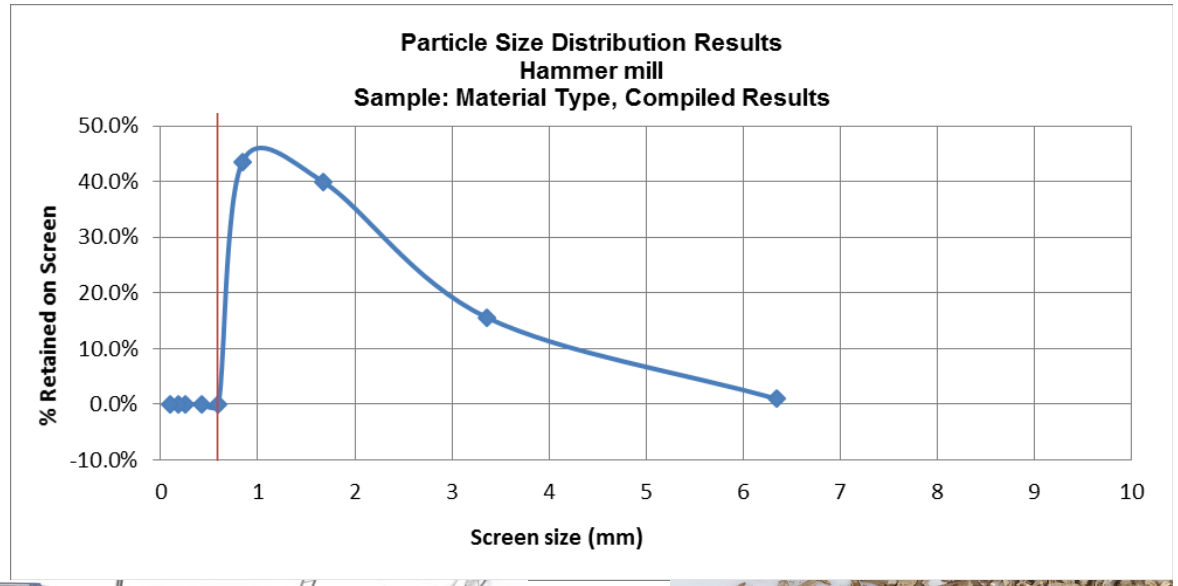




Results

Particle size distribution





Results

	Milling Energy kWh/dry ton	Drying Energy kWh/dry ton	Air Handling / Dust Collection kWh/dry ton	Total Energy Consumed kWh/dry ton
Crumbler Rotary Shear	18.4	1220	2.0	1238
Hammer mill	11.2	2314	2.0	2330

Energy summary for hammer milled hardwood chips

	Recirculated	Lost Fines	Accepts	Particle Size	Aspect Ratio
Crumbler Rotary Shear	17.6%	1.1%	81.3%	5.2 mm	5.0
Hammer mill	0%	35%	65%	2.3 mm	9.1

Energy summary for Crumbler rotary shear milled hardwood chips

Results

Equipment	Ownership Cost ($/dry ton)	Operating Cost ($/dry ton)	Lost Material Cost ($/dry ton)	Total Cost ($/dry ton)
Dryer	$1.31	$45.39	$0.00	$46.70
Hammer mill	$0.89	$3.71	$46.17	$50.77
Conveyors	$0.05	$0.04	$0.00	$0.09
Dust Collection	$0.18	$0.66	$0.00	$0.84
Total	$2.64	$49.80	$46.17	$98.40

Cost summary for hammer milled hardwood chips

Equipment	Ownership Cost ($/dry ton)	Operating Cost ($/dry ton)	Lost Material Cost ($/dry ton)	Total Cost ($/dry ton)
Rotary Shear	$2.50	$3.32	$0.67	$6.49
Dryer	$1.31	$24.40	$0.00	$25.71
Conveyors	$0.05	$0.04	$0.00	$0.09
Dust Collection	$0.16	$0.65	$0.00	$0.81
Total	$4.02	$28.41	$0.67	$33.10

Cost summary for Crumbler rotary shear milled hardwood chips

Summary

- Size reduction before drying = significant drying energy savings
- Rotary shear produces more uniform particles
- Rotary shear produces more lower aspect ratio particles
- Cost savings as tested $65.30 / dry short ton for rotary shear
- Potential biorefinery savings of $52.24 million per year

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Thank You

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