Micronized Wood and Clean Sugar Technology and Depot TEA from Forest Residuals

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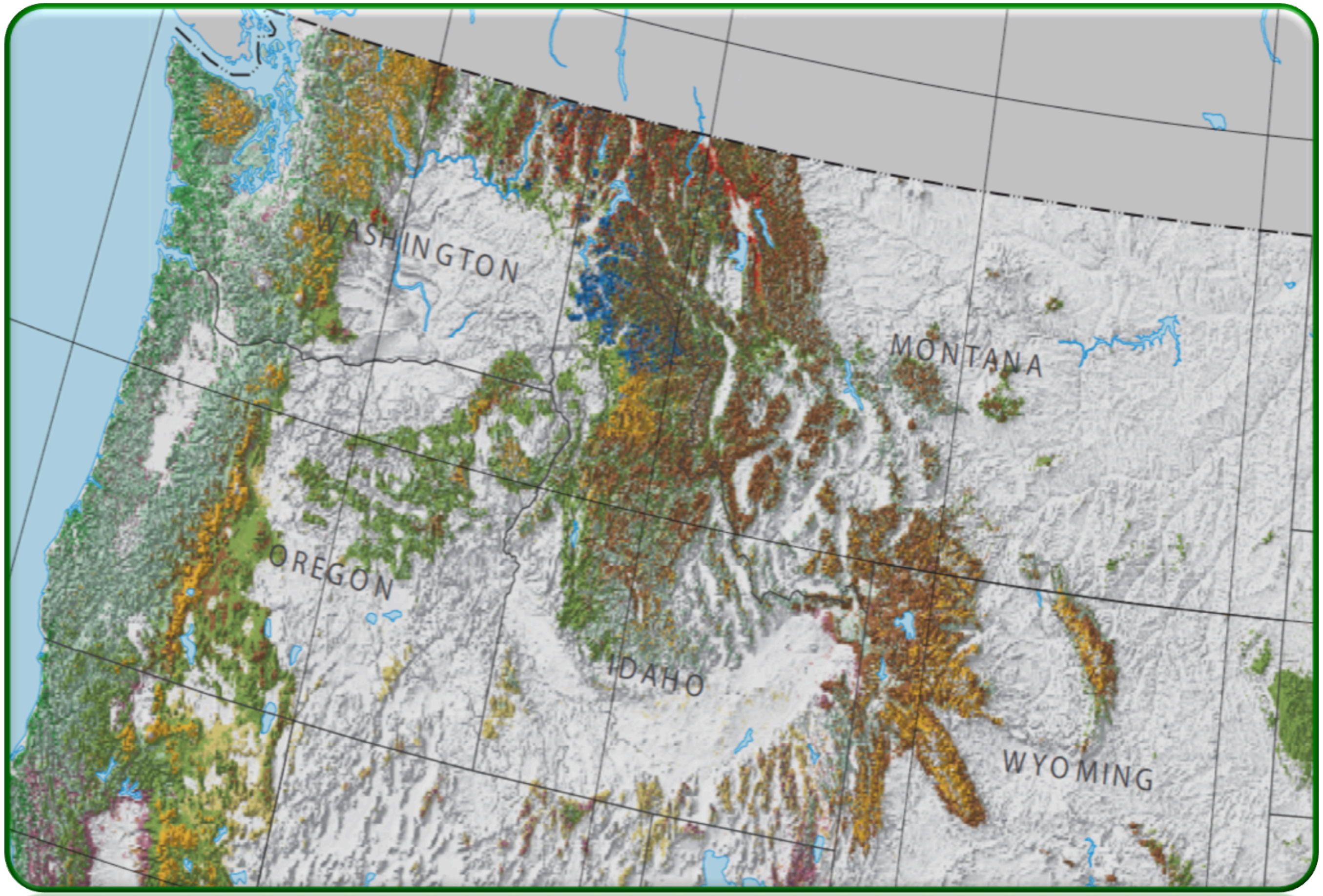
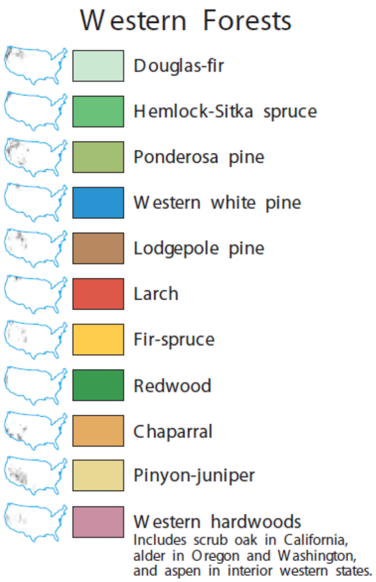
Outline

- Forest Map in Northwest
- Industrial Feedstocks from Forest Residuals
- Wood Micronization Technology for Sugar and Lignin Production
  - **Pretreatment options**
  - **Wood micronization & sugar production**
  - **Energy requirement in micronization**
- Depot Model for Sugar and Fuel Pellet Production
- Summary

Softwood Distribution in US NW

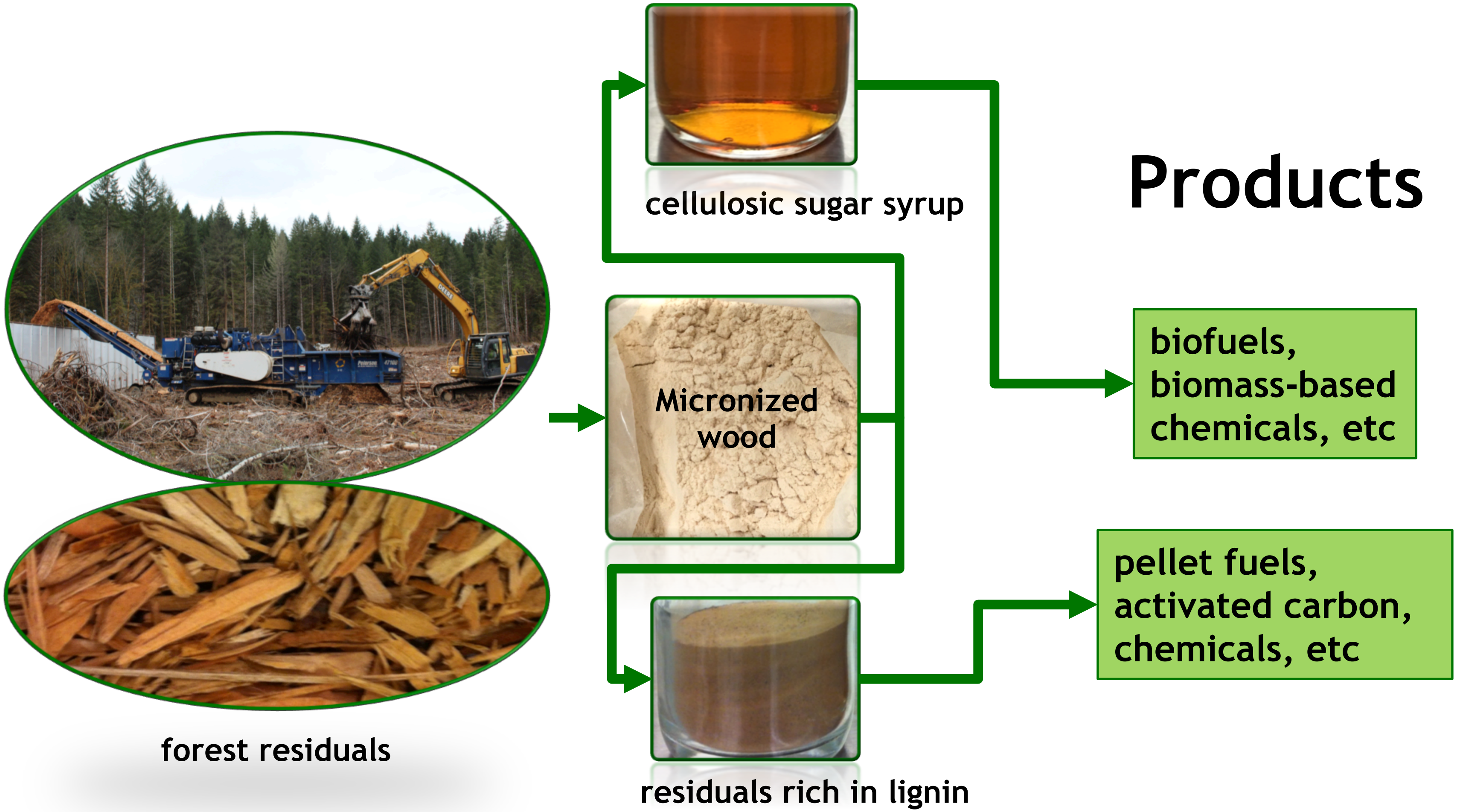




Sustainable US forest residuals and wood wastes: >75 million tons/yr – about 5 billion gal/yr cellulosic ethanol, or 2.8 billion gal/yr hydrocarbon fuels.

Reference: (1) Forest cover types by US Forest Service, http://www.fia.fs.fed.us/; (2) US DOE, 2011. US Billion-Ton Update, Biomass Supply for a Bioenergy and Bioproducts Industry

Industrial Feedstocks from Forest Residuals



Cellulosic sugar and lignin rich residuals as new forest feedstocks?

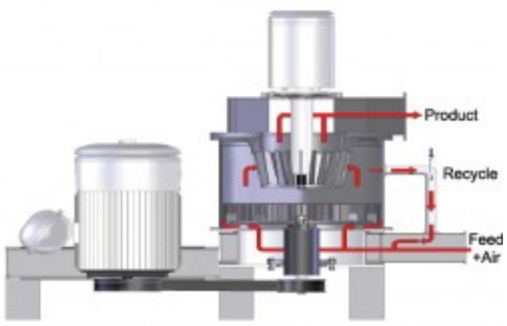
Pretreatment Review

- Current chemical pretreatment technologies on softwood biomass
  - Chemicals (e.g. bisulfite)
  - Organic solvent (e.g. alcohol)
  - Acid (e.g. H_2SO_4, HCl)
- Disadvantages of chemical pretreatment
  - Chemical & recycling cost
  - Neutralization & $CaSO_4$ disposal
  - Inhibitor formation in pretreated biomass
  - Environmental concerns (air permit, waste treatment, and water usage)
  - Chemical impurities brought into lignin; modified lignin.

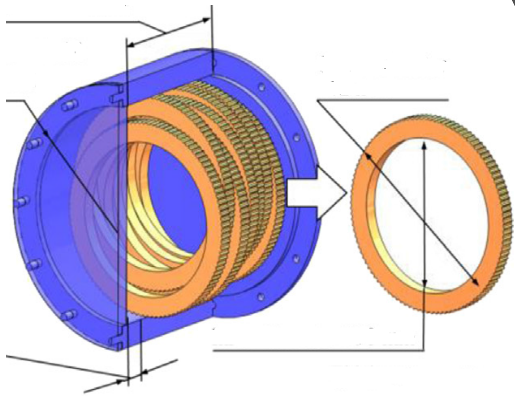
Chemical pretreatment could be efficient but could post more cost and environmental concerns.

Alternative Pretreatment: Micronization

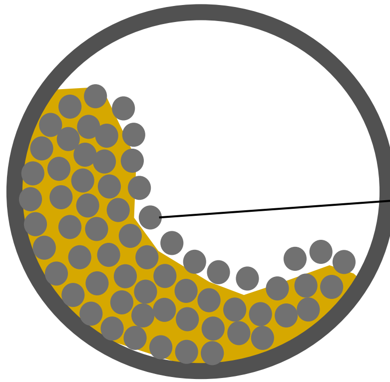
air classifying milling (ACM)



ring milling



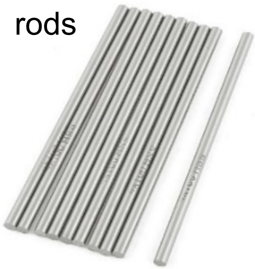
media milling (MM)



media types:

balls

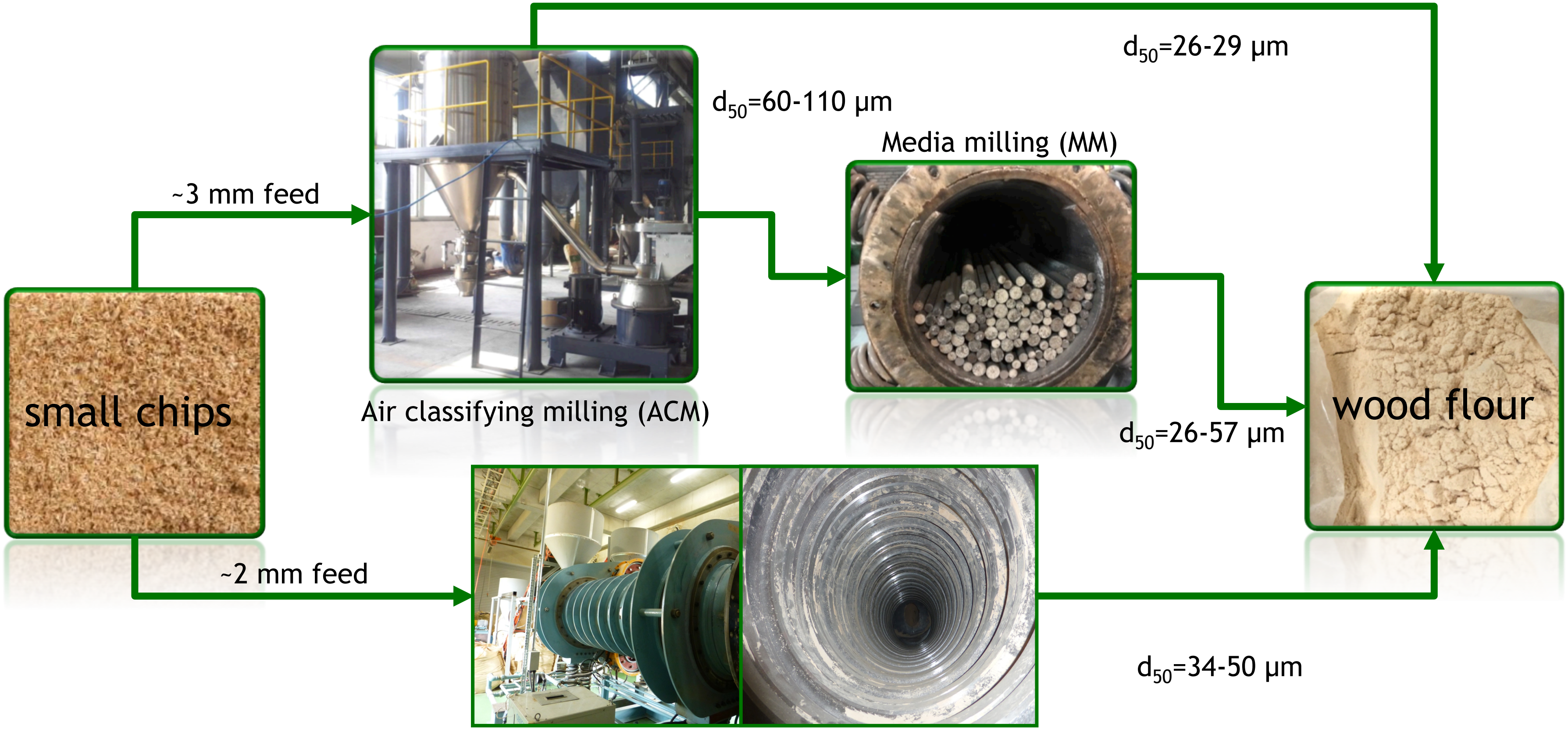
rods



cylpebs

Mechanical milling could be an efficient pretreatment method; how to reduce energy consumption?

Micronizing Trials: Ring Milling; Air Classifying Milling & Media Milling



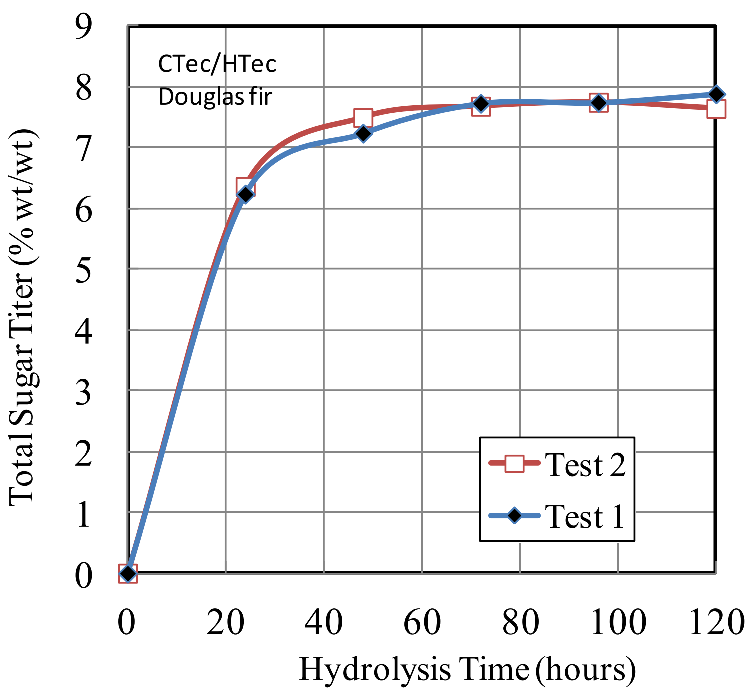
1st prototype large scale tandem ring milling - TRM (12-48 kg capacity)

Air classifying milling is an effective method of achieving size reduction, however ring & media milling is superior for amorphization.

Acknowledgement: Tandem ring milling was developed in Dept. of Machine Intel. and Sys. Eng., Akita Prefectural University (APU) by Drs. and Profs. Hideaki Mori and Takehiko Takahashi and his team, and Douglas-fir milling trials were kindly supported by Prof. Mori and his team.

Enzymatic Hydrolysis of Micronized Wood

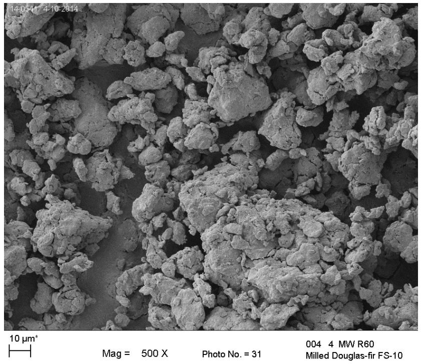
Hydrolysis Profile of Small Scale Micronized Wood



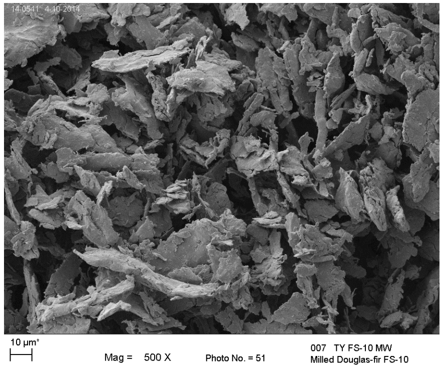
Conditions: Small scale-milled Douglas-fir (60 min); 20.6% solid in hydrolysis with 6.6% (wt/wt) enzyme dose at 50°C and pH ~5.2-5.0.

Total Sugar Yields of Large Scale Micronized Douglas-fir (FS-01) at Different Solid Load with Various Enzyme Dosages

Large Scale Milling Trial	Solid Load (%)	Enzyme Dose (wt/wt %)	72-hr Hydrolysis Sugar Yield (%)	72-hr Sugar Titer (%)	96-hr Hydrolysis Yield (%)	96-hr Sugar Titer (%)
12 kg	19.3	5.5	59.4	7.9	60.7	8.1
24 kg	17.5	5.5	47.0	5.8	49.1	6.0
36 kg	17.5	5.5	40.3	5.0	42.2	5.2
48 kg	17.5	5.5	36.0	4.4	36.8	4.5



60-minute Tandem-Milled Douglas-fir



Continuous ACM-Milled Douglas-fir

TRM micronized softwood is readily hydrolyzable at high solid loading

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Integrated Process Design & Test

~ 2 mm

~ 34-50 μm

milled/micronized softwood hydrolysis provides clean sugar and lignin streams

wood chipping → resizing → drying → fine milling

hydrolytic enzymes, water → hydrolysis → coarse filtration → fine filtration → Low sulfur & no-furan clean sugar stream

coarse filtration → low sulfur lignin-rich residuals

fine filtration → low sulfur lignin-rich residuals

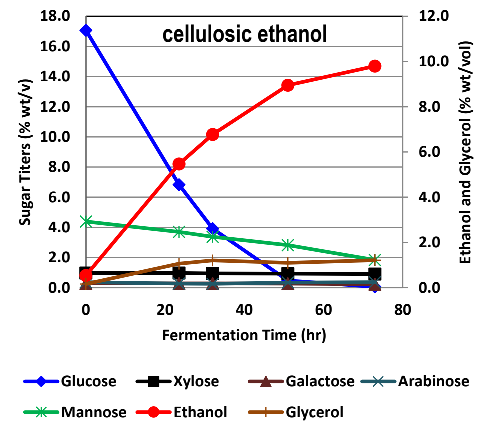
Low sulfur & no-furan clean sugar stream → Concentra-ting → low sulfur & no-furan clean sugar syrup

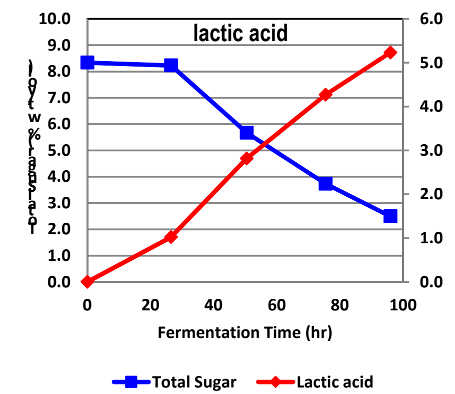
Concentra-ting → drying or crystalliza-tion → low sulfur & no-furan dry clean sugar

no furan & low sulfur 0.016%

Lignin 46-54%
low sulfur 0.055-0.068%

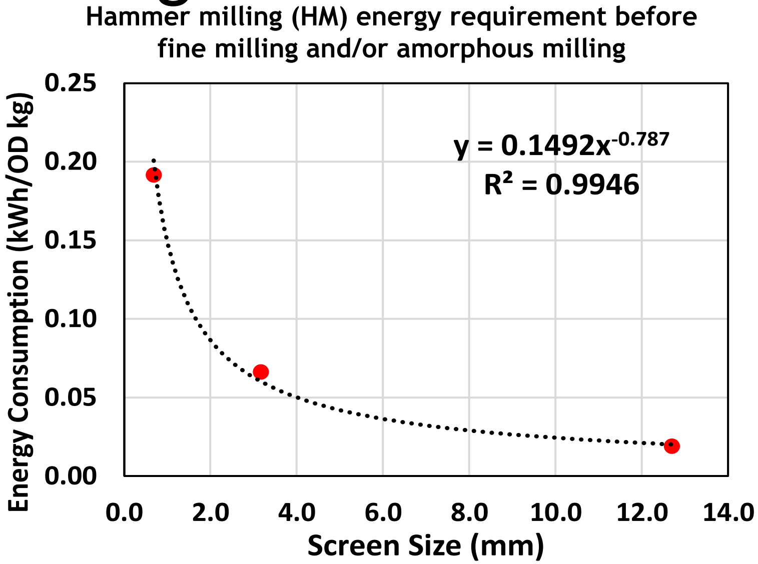
Clean Sugar Application Examples

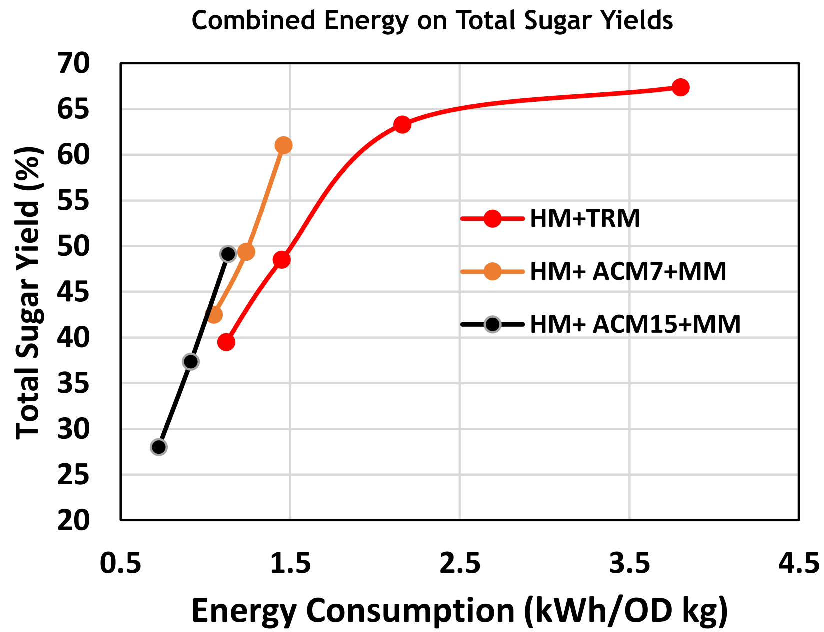


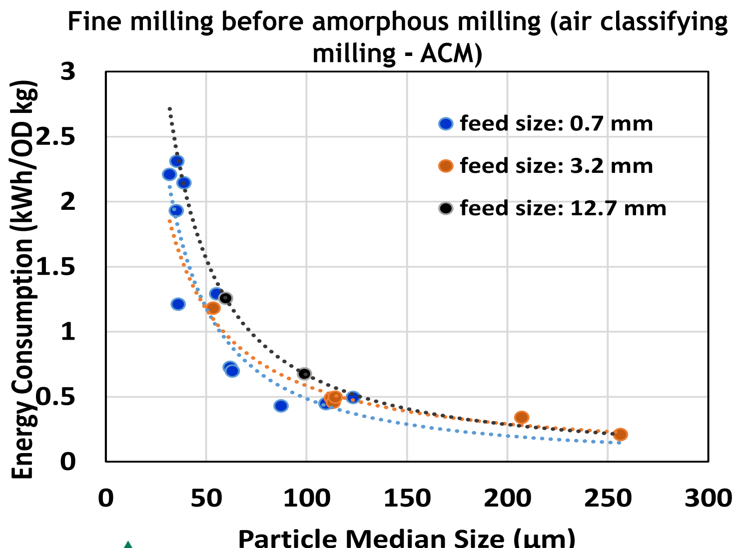


Reference: Gao J, Neogi, A. 2014

Energy Evaluation: Hammer, ACM & Media Milling







Three-step milling is more effective milling by the combination of HM +ACM+MM, while HM+TRM could be optimized.

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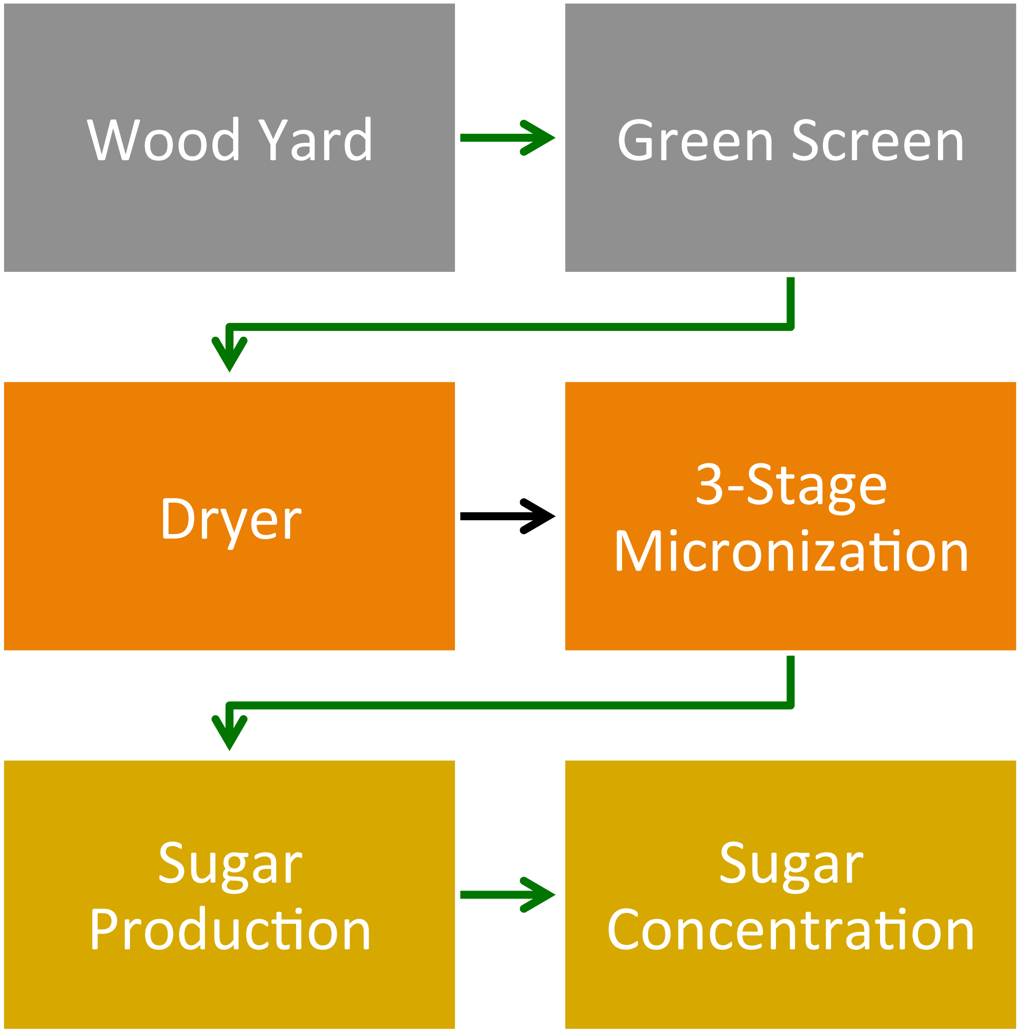
Depot Flow Chart of Micronized Wood & Sugar Production



Variables for Micronized Wood and Sugar Facilities

Sugar Yields under Various Conditions

Scenario	Sugar Yield (kg/kg)	Milling Energy (kWh/ OD kg)
Pessimistic	0.181	1.46
Base	0.328	1.46
Optimistic	0.378	1.62

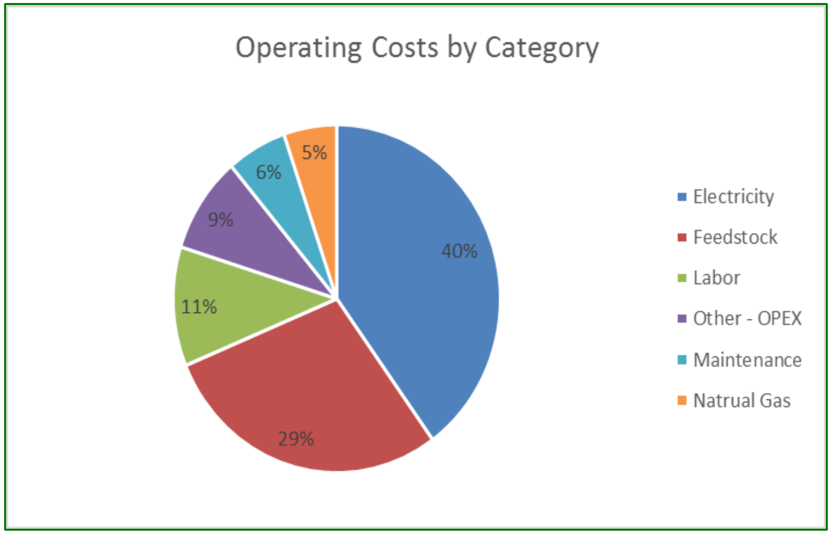
Base Case Variables

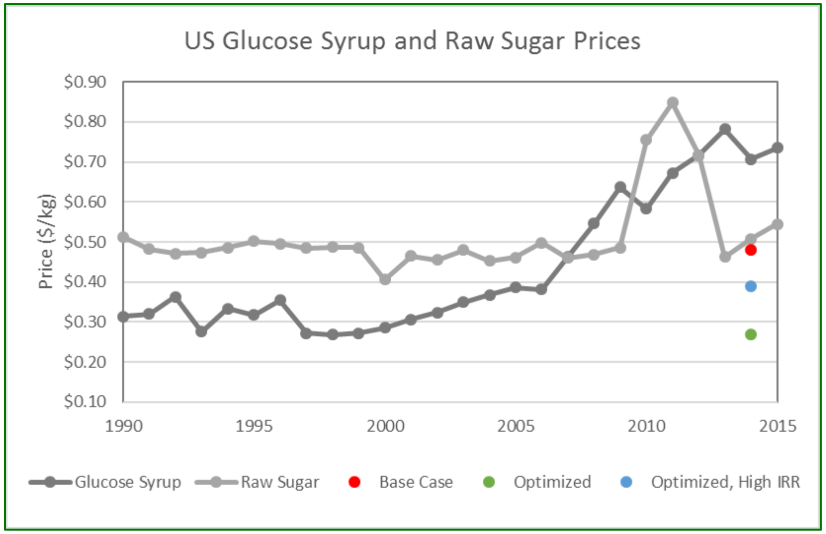
Variable	Unit	Base Case Value
Total Milling Electricity	kWh/OD kg	1.46
Median Micronized Wood Particle Size	µm	25
Electricity Rate	$/kWh	0.056
Natural Gas Rate	$/MMBtu	8.29
Feedstock Cost, Delivered	$/BDMT	49.41
Sugar Yield from forest harvest residuals (FHR)	kg sugar/kg FHR	0.33
Fuel Pellet Yield	kg fuel pellets/kg FHR	0.68

Draft data to be finalized; not to be quoted.

Micronization and Saccharification Facilities Cost Analysis

Percentage of operating costs by category for 276 BDMT/yr micronizing facility





Items	Micronized Wood Facility	Concentrated Sugar Facility	Non-Concentrated Sugar Facility
TCI (MM $)	85.7	55.4	39.2
Annual Operating Cost (MM$)	47.4	75.2	72
Annual Sugar Yield (k BDMT/yr)	NA	90.3	90.3
Annual Fuel Pellet Yield (k BDMT/yr)	NA	188.2	188.2
IRR	0%	10%	10%
MSSP ($/kg)	NA	0.485	0.411

Draft data to be finalized; not to be quoted.

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Summary

- Technologies are being developed for no-chemical and no-water softwood pretreatment by micronization for clean cellulosic sugar production.
- No inhibitors (HMF and furfural) and no chemicals greatly benefit all types of fermentation (yeast or bacteria).
- Extremely low-sulfur sugar & lignin products allows much wider application through bioconversion and direct catalytic conversion to fuel and co-products:
  - **e.g. ethanol, butanol, isobutanol, IPK, lactic acid, other organic acids, solid fuel, fuel additives, polymer precursors, among others.**
- Process simplicity could benefit depot style facilities, resulting in competitive feedstocks (sugar and lignin-rich materials). Large scale pilot at bdt/hour needs to be demonstrated.

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  Jinxue Jiang and Yalan Liu who help us characterize the micronized wood powders.

- Forest Concepts LLC, Auburn, WA

  Their support in wood chip resizing to ~2 mm chips.


"Releasing the potential in trees to solve important problems for people and the planet"
Sustainable Forest
Forest Residuals in Part
Clean Cellulosic Sugar, Higher Energy Fuel Pellet & Activated Carbon