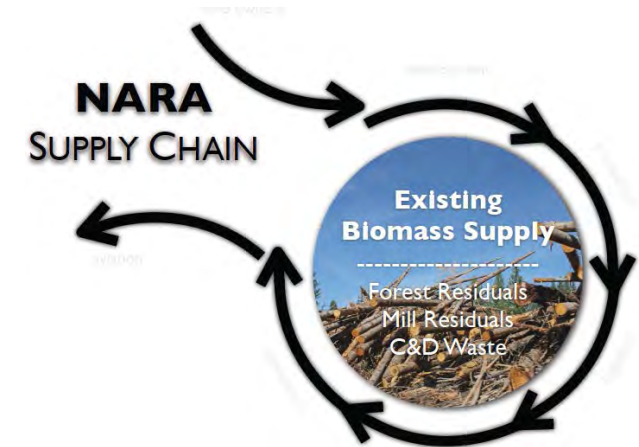
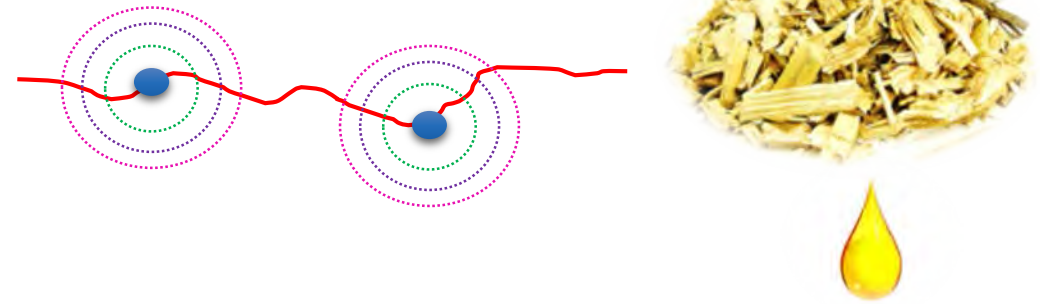


# Engineering and Economic Considerations of Renewable Energy Production from Forest Residues



## POINTS OF DISCUSSION

- 1) What are the main factors that affect the cost of feedstock?
- 2) What is the impact of the main factors across the supply chain?
- 3) How does freshness of biomass affect sugar yield?
- 4) How does freshness of biomass affect bulk density?
- 5) How does freshness of biomass affect comminution costs?
- 6) How does freshness of biomass affect collection costs?

# Forest residues and feedstock preparation

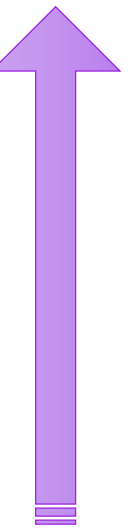


Biofuel

Sugars

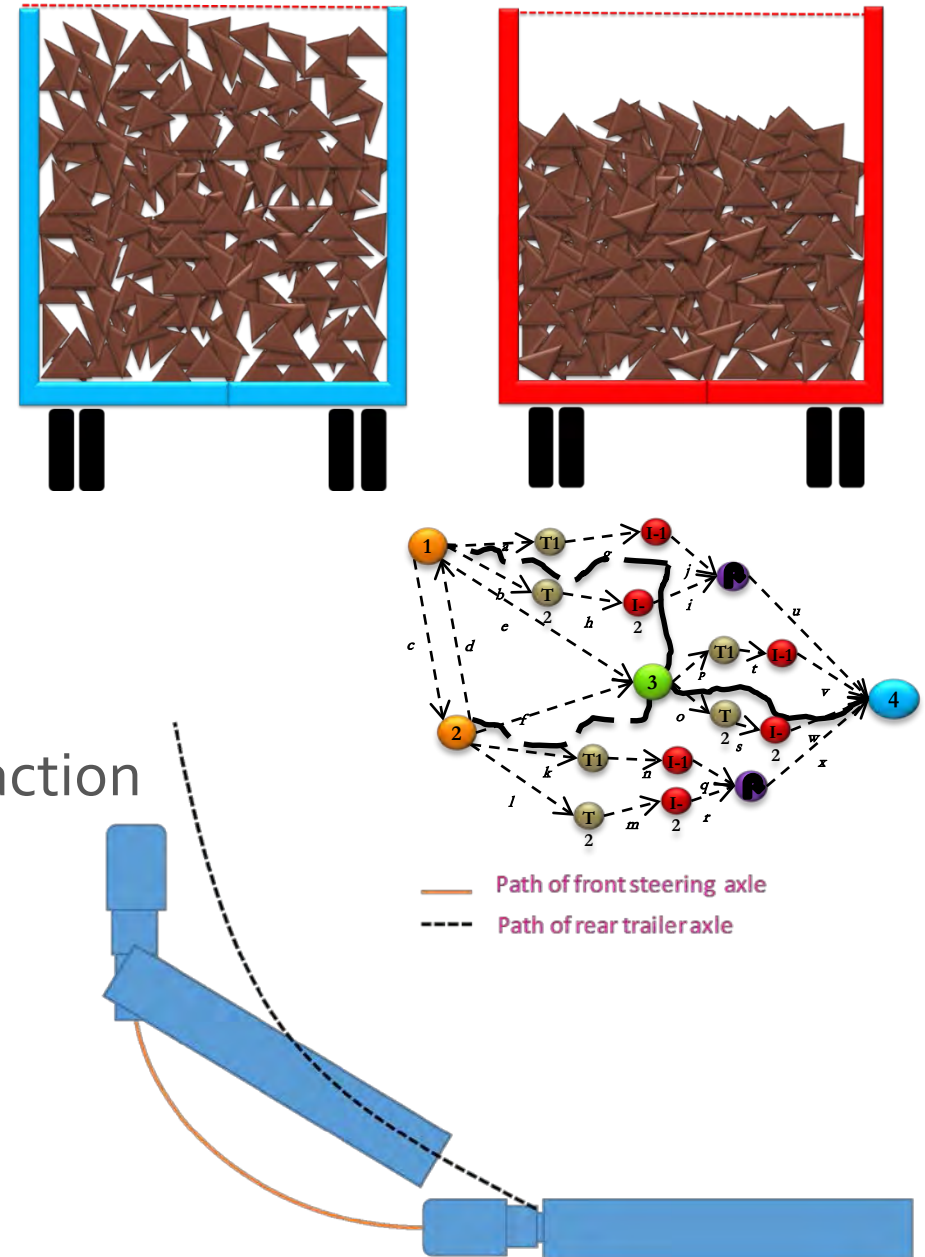
Grindings

Forest  
Residues

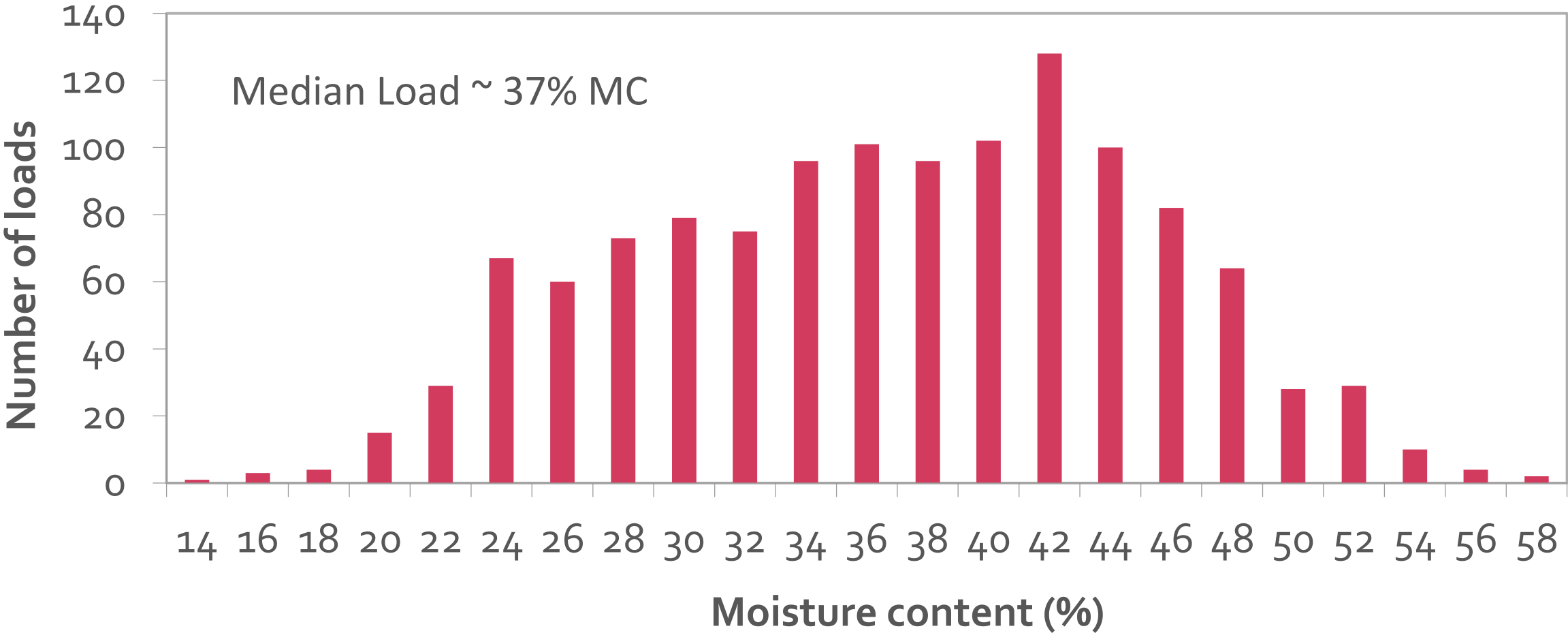


## FACTORS AFFECTING COST

- Piece size of residue
- Particle size of grindings
- Capacity of truck
- Collection distance
- Operational settings --> truck-machine interaction
- Fresh or aged
- Amount of sugars



# Moisture Content in Biomass Deliveries to Seneca Cogeneration Plant 2013-16



# Harvest Sites near Dexter, Oregon, USA



# FRESH AND AGED FOREST HARVEST RESIDUES

MC = 60% Wet Basis

Bark & Needles = 16.7% of Dry Mass



MC = 15% Wet Basis

Bark & Needles = 6.2% of Dry Mass



# FRESH HARVESTED BIOMASS

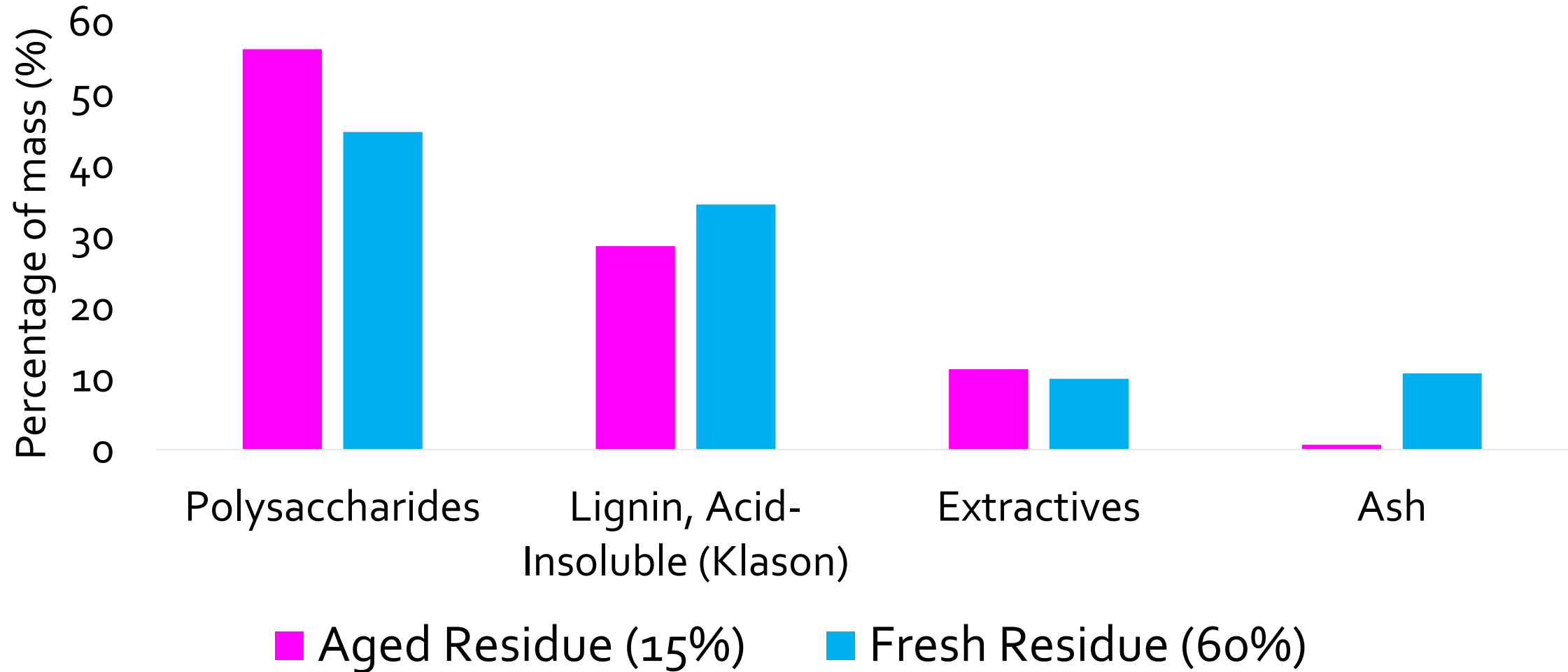
a)



b)



# POLYSACCHARIDES LABORATORY ANALYSIS



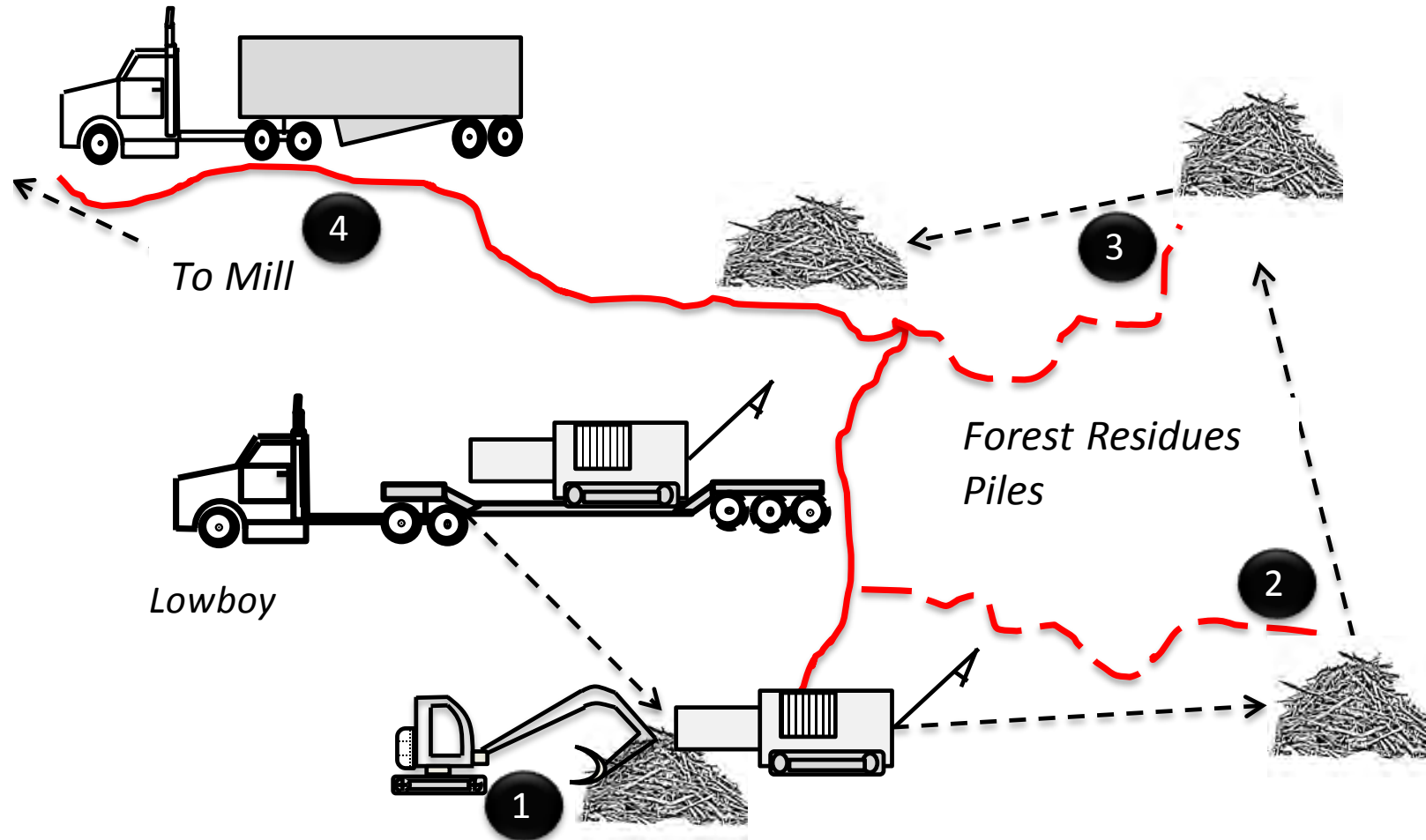
# VALUE DIFFERENCE COMPONENTS AT MILL

- From Analytical Test: 26% more residues need to be delivered to provide the same amount of sugar from fresh residues.
- The greater the sum of collection + grinding + transportation distance (cost), the greater the cost penalty from the reduced sugar yield

## VALUE DIFFERENCES DUE TO SUGAR CONTENT FOR A \$70/ODT DELIVERY COST FOR FRESH AND AGED FEEDSTOCK

	Fresh	Aged
Total polysaccharides, % on feedstock	44.6%	56.3%
Hydrolysis yield, as polysaccharides to feedstock polysaccharides, %	89.2%	89.2%
Sugars as polysaccharides, ODT per ODT feedstock, %	39.8%	50.2%
Sugars as monomers, ODT/ODT, %	35.8%	45.2%
Assumed delivered cost of feedstock, \$/ODT	70	70
Feedstock cost per kg of sugar monomers	0.195	0.155

# Comminution and Transport

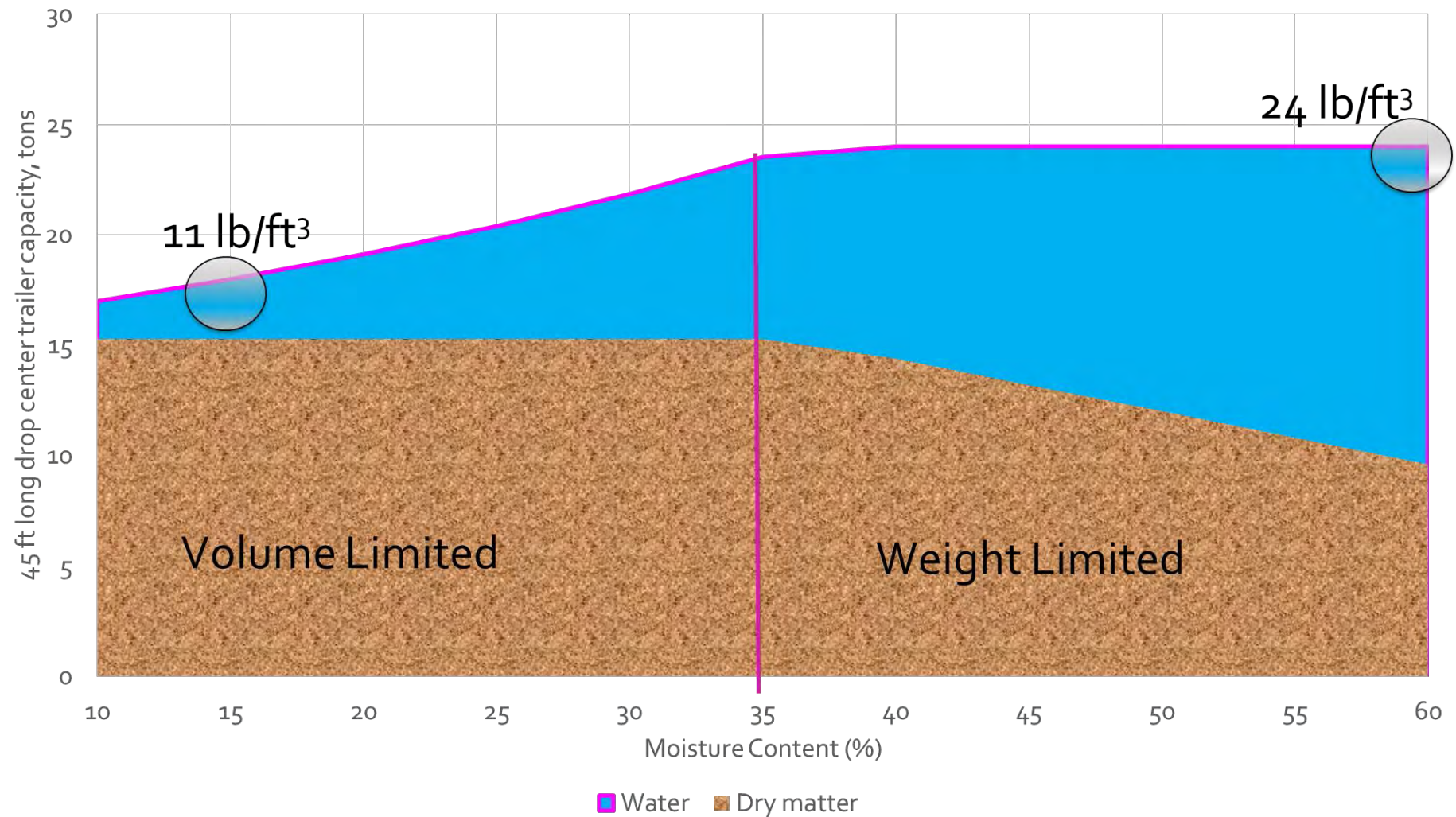


# TRANSPORTATION COST

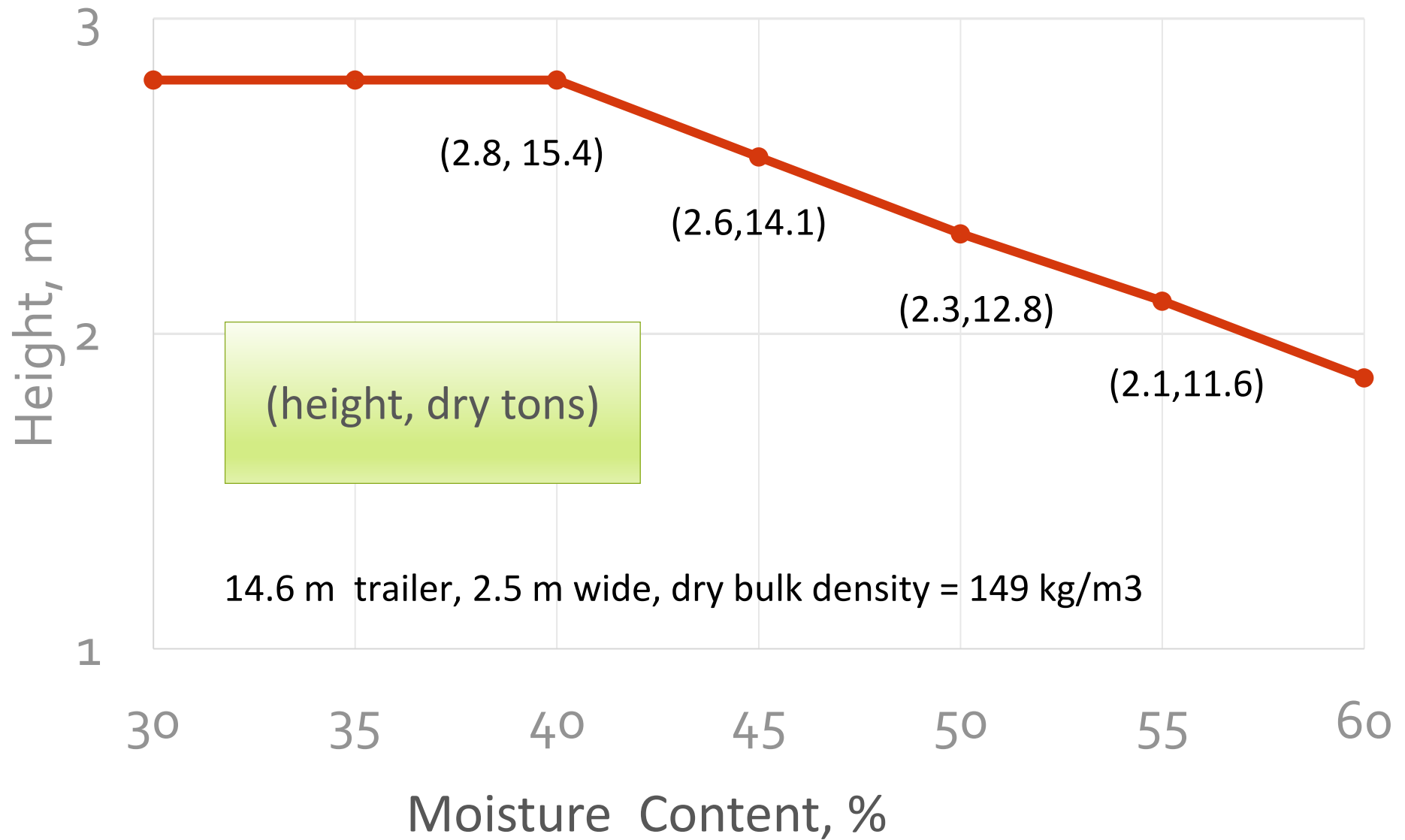
Road Surface	Loaded USD h <sup>-1</sup>	Unloaded USD h <sup>-1</sup>	Idling USD h <sup>-1</sup>
Gravel	86.3	77.6	50.0
Paved	118.4	100.0	50.0

6 x 4 Truck with 130 cy capacity trailer, 45 miles/hr paved (Average), 10 miles/hr gravel

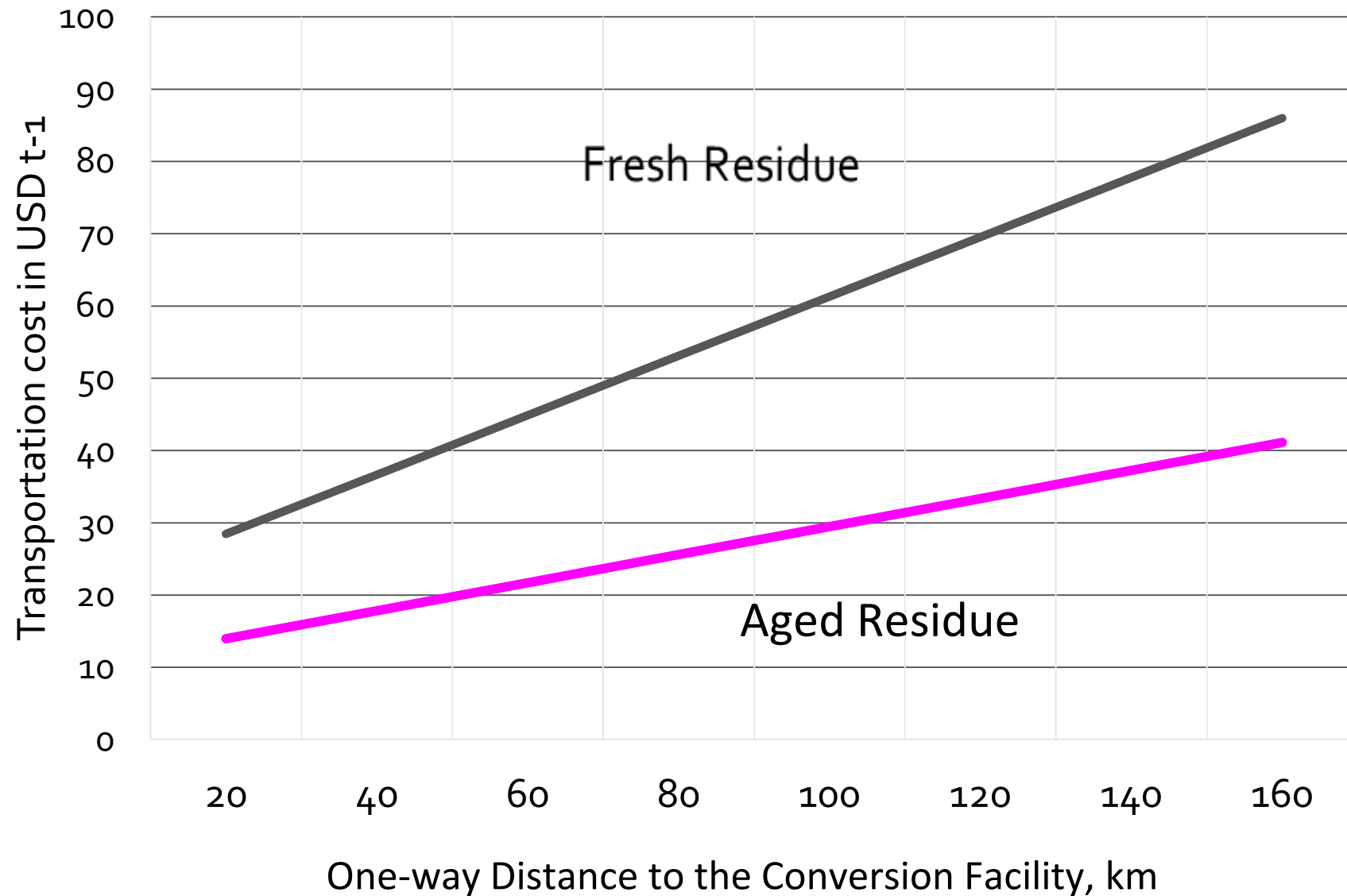
# MOISTURE CONTENT



# RESIDUE HEIGHT IN TRAILER



# Transportation Cost of Fresh and Aged Residues



# COMMINUTION

## Fresh Biomass (60% MC)

Bulk Density = 388.1 kg/m<sup>3</sup>

Fuel Consumption = 1.0 L/GT

### Simulation Results

100% Productivity = 69.5 GT/hr

100% Productivity = 41.7 ODT/hr

66% Productivity = 27.6 ODT/hr

## Aged Biomass (15% MC)

Bulk Density = 184.2 kg/m<sup>3</sup>

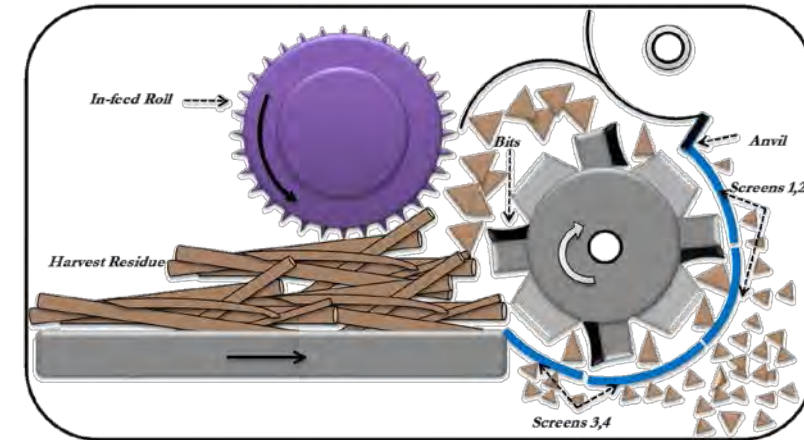
Fuel Consumption = 2.2 L/GT

### Simulation Results

100% Productivity = 49.6 GT/hr

100% Productivity = 41.2 ODT/hr

80% Productivity = 32.9 ODT/hr



Grinder Utilization for Fresh Biomass Lower Due to Increased Waiting Time due to Greater Number of Trucks Per Hour

## COMMINUTION COSTS (750 HP GRINDER + LOADER)

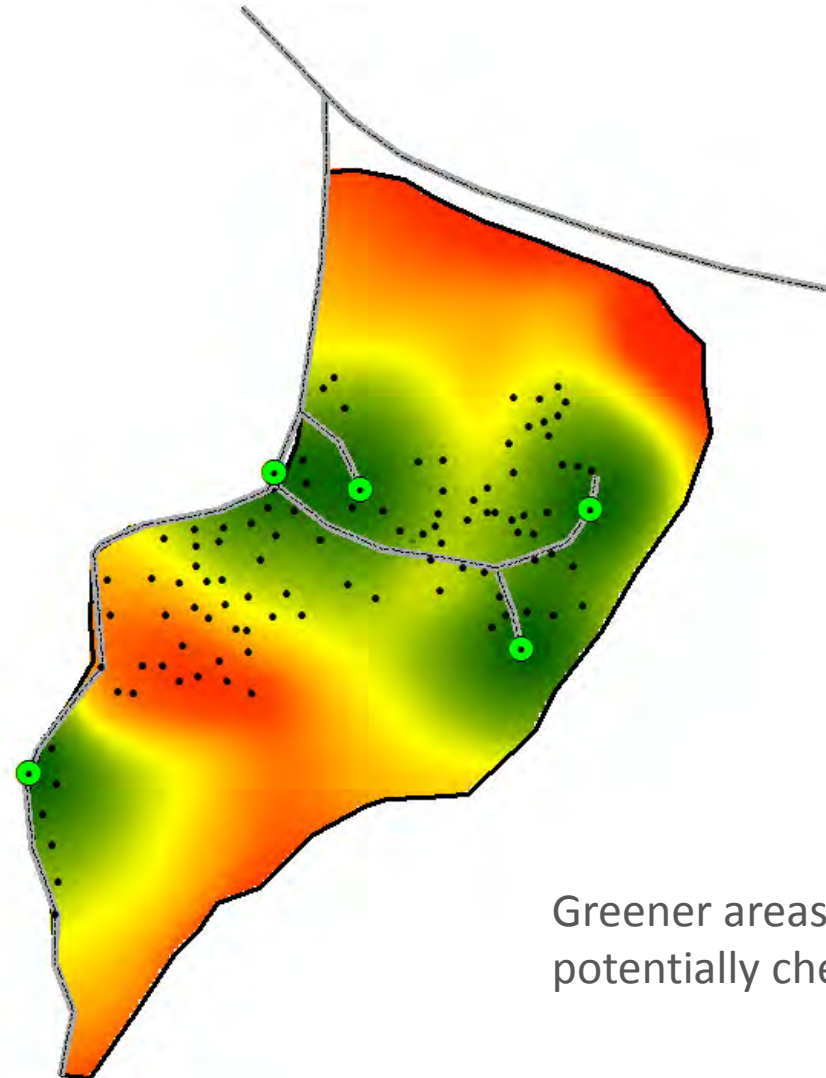
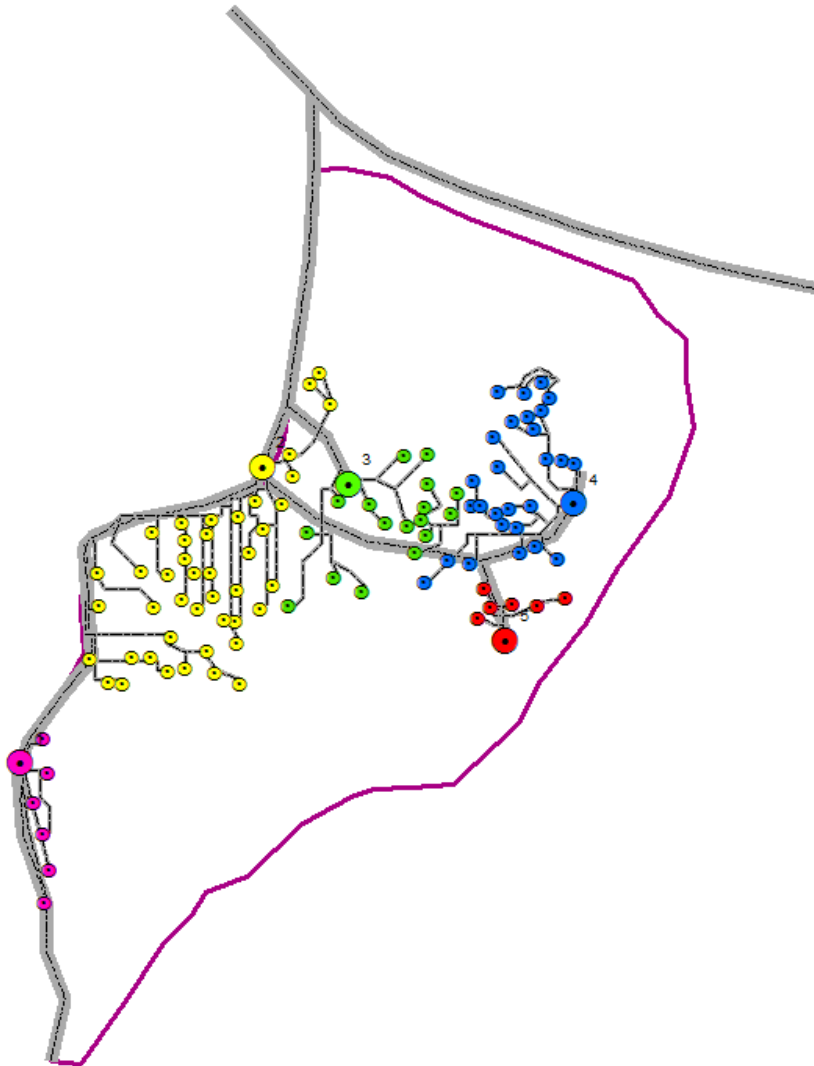
### Fresh Biomass

- Operating Cost with Fuel = \$357/hr
- Idle Time = \$116/hr
- 66% Productivity = 27.6 ODT/hr
- Cost/ODT = \$10.0

### Aged Biomass

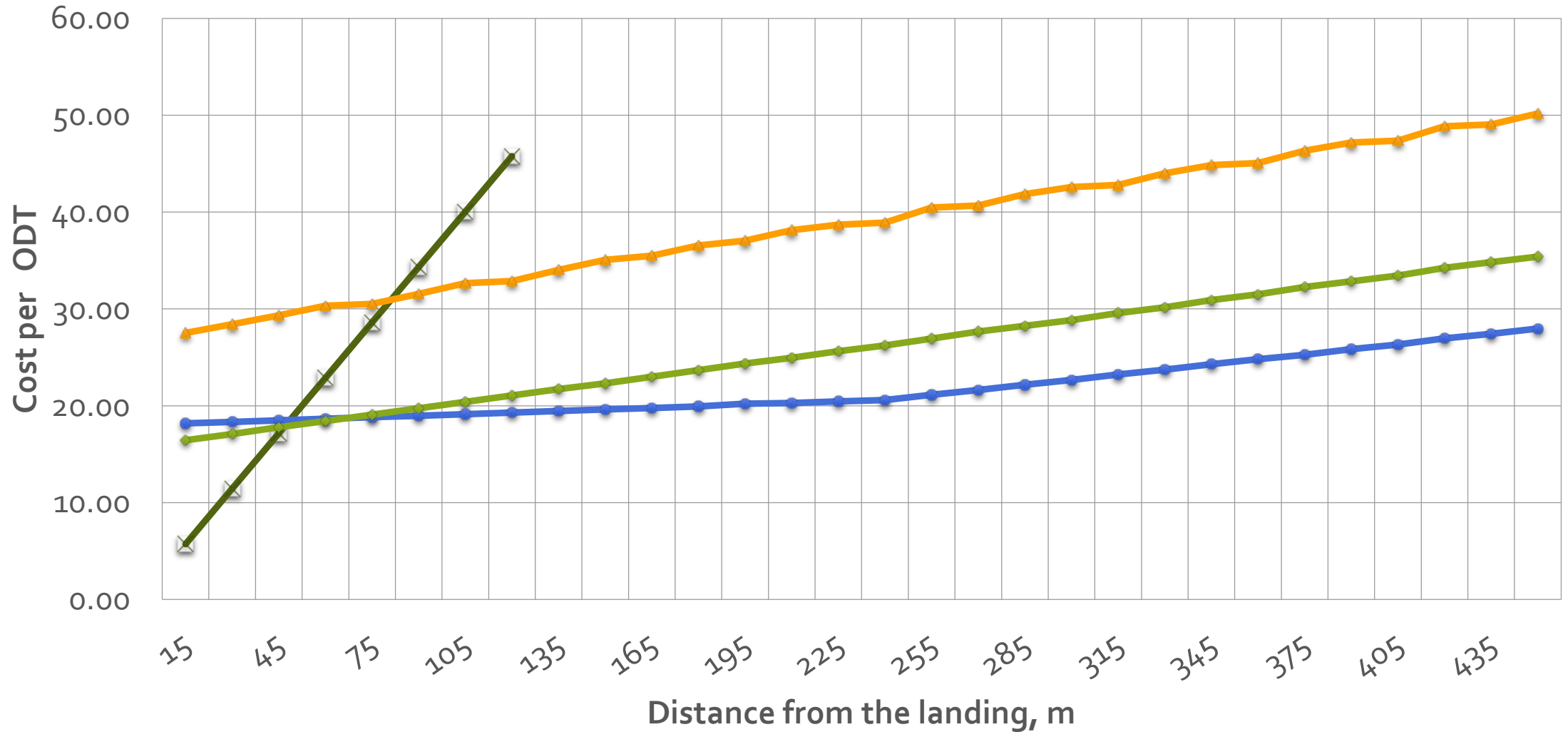
- Operating Cost with Fuel = \$406/hr
- Idle Time = \$116/hr
- 80% Productivity = 32.9 ODT/hr
- Cost/ODT=\$10.6

# COLLECTION



Greener areas indicate  
potentially cheaper biomass

# COLLECTION COST



✕ System 1: 1-Loader only

● System 4: 2-Forwarders & 1-Loader

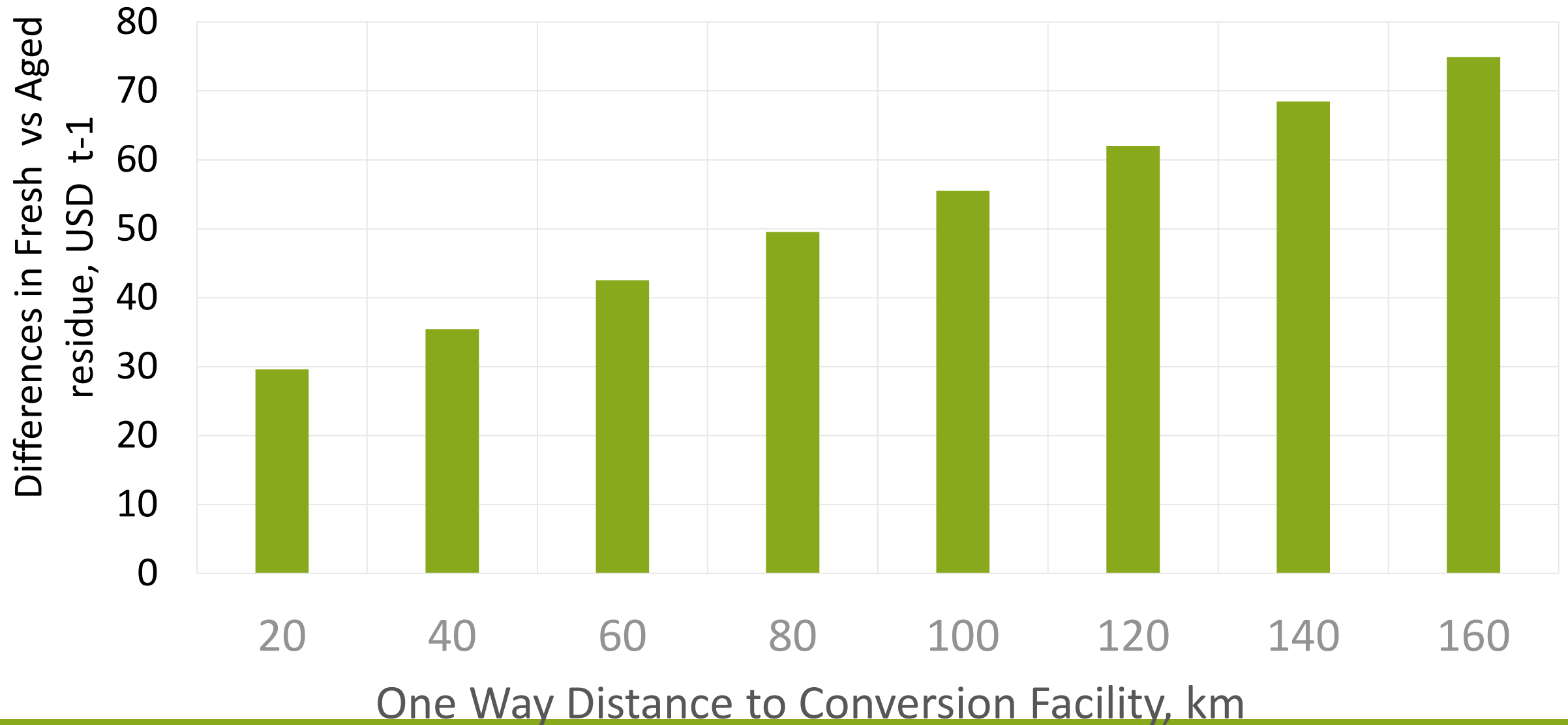
▲ System 2: 1-Forwarder & Self-Loading

◆ System 3: 1-Forwarder & 1-Loader

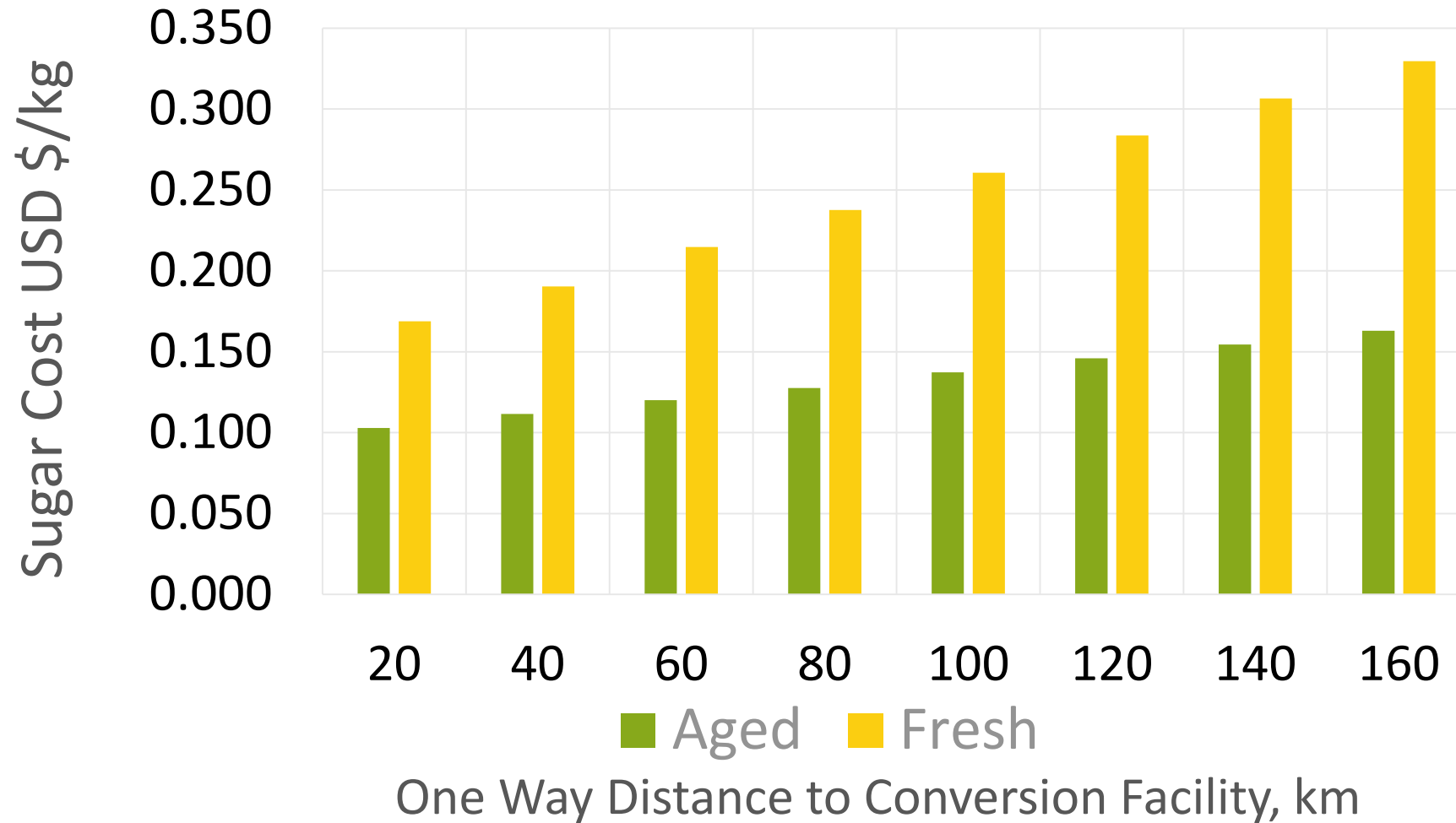
# Fresh and Aged Residue Delivery Costs and Sugar Penalty

One-Way	Collect	Grind	Grind	Transport	Transport	---Cost to Mill -----		Sugar	Difference	-----Sugar Cost-----	
km		Aged	Fresh	Aged	Fresh	Aged	Fresh	Penalty		Aged	Fresh
	\$/ODT	\$/ODT	\$/ODT	\$/ODT	\$/ODT	\$/ODT	\$/ODT	\$/ODT	\$/ODT	\$/kg	\$/kg
20	22.00	10.60	10.00	13.95	28.44	46.55	60.44	15.71	29.60	0.103	0.169
40	22.00	10.60	10.00	17.83	36.15	50.43	68.15	17.72	35.44	0.112	0.190
60	22.00	10.60	10.00	21.72	44.88	54.32	76.88	19.99	42.55	0.120	0.215
80	22.00	10.60	10.00	25.10	53.10	57.70	85.10	22.13	49.53	0.128	0.238
100	22.00	10.60	10.00	29.48	61.32	62.08	93.32	24.26	55.50	0.137	0.261
120	22.00	10.60	10.00	33.36	69.54	65.96	101.54	26.40	61.98	0.146	0.284
140	22.00	10.60	10.00	37.24	77.76	69.84	109.76	28.54	68.46	0.155	0.307
160	22.00	10.60	10.00	41.12	85.98	73.72	117.98	30.67	74.93	0.163	0.330

# DIFFERENCE IN FRESH AND AGED RESIDUE COST INCLUDING COLLECTION+GRINDING+TRANSPORT+SUGAR YIELD PENALTY

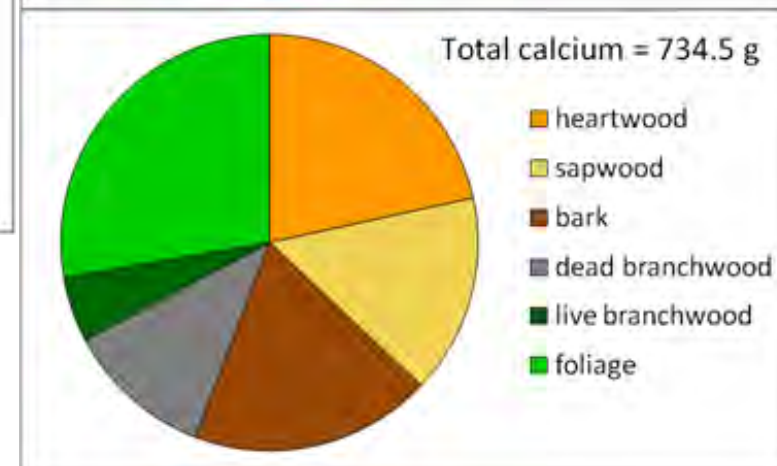
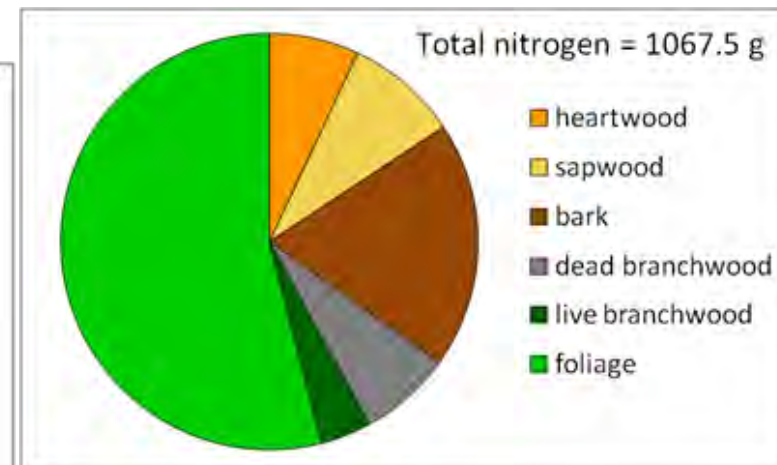
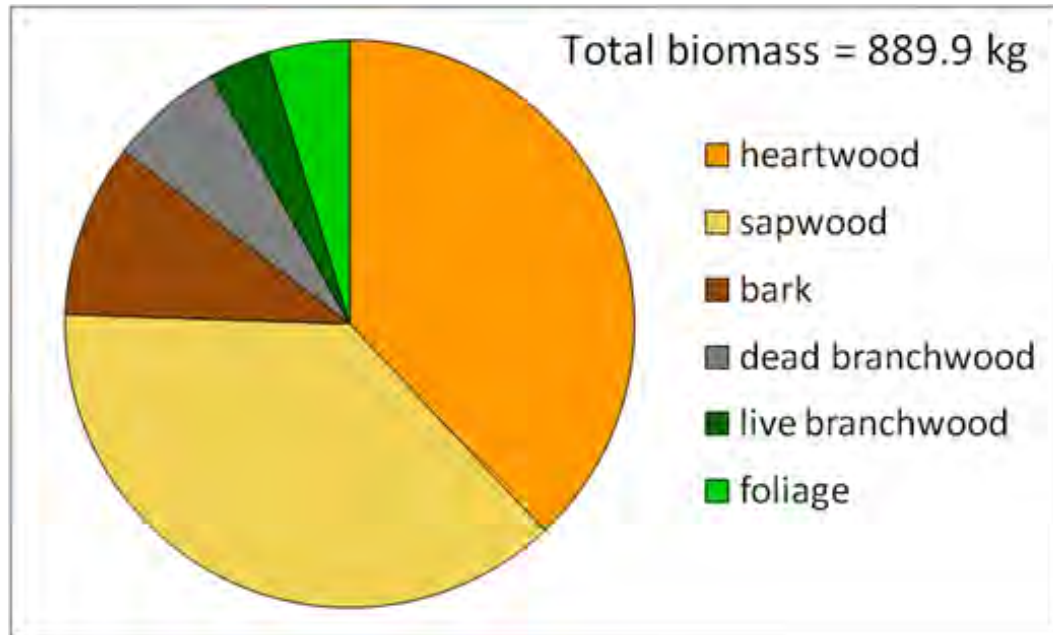


## SUGAR COST DIFFERENCES BY DISTANCE



# TOTAL ABOVEGROUND NUTRIENTS

Douglas-fir tree, 38 yrs old  
dbh=45.6 cm, height =33.5 m, crown length =19.9 m



Mainwaring, Maguire, and Harrison, NARA  
Annual Meeting, 2015, Spokane, WA

# Conclusions from the Engineering and Economic Perspective

Mill site

Aged more valuable  
du to higher sugar  
yield

Transport

Aged residues much  
less expensive

Comminution

Aged slightly more  
expensive but few  
differences

Operational  
setting

Few truck loads less  
impact on roads

Collection

No difference: Volume  
limited

Environmental

Needles nutrient  
content important to  
left in the field

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# Questions?



Oregon State University, NARA, 2016

