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Lignocellulosic Biomass Attributes for a Uniform Format Feedstock Supply System: The Logistical Challenges of Large Scale Biomass

Agricultural Outlook Forum
Washington DC
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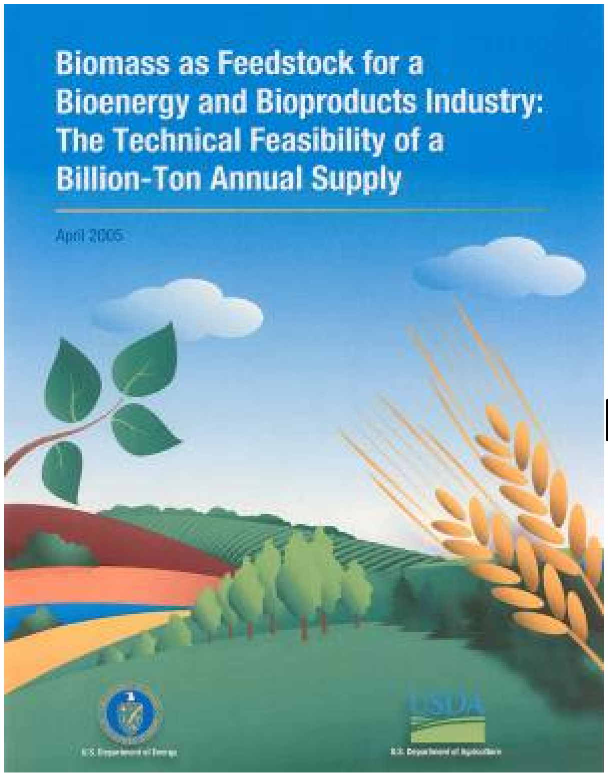
DOE Biorefining Industry 2030 Goals

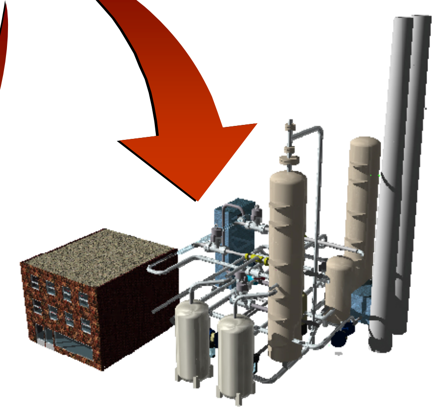
Displace a significant fraction of gasoline demand ~ 60 billion gallons/year by 2030



http://bioenergy.ornl.gov

~1.3 Billion tons/yr Biomass Potential in the U.S.

Sugar Platform



Syngas Platform

Including Corn Grain, an <u>Estimated 600 – 700 Million Tons</u> of Biomass per Year is Needed for 60 B gal of ethanol.

Evaluating Progress: Biomass Feedstock Cost Target and Metrics

$$\$/\text{ton} = \left(\text{Grower Payment } [\$/\text{ton}]\right) + \left(\frac{\text{Efficiency } [\$/\text{hr}]}{\text{Capacity } [\text{ton/hr}]} + \text{Quality } [\$/\text{ton}]\right)$$

Therefore

$35-75/ton = $10-$50/ton + $25/ton

2012 Industry initiation/low demand Cost Target (2002$)

Supply and Demand Drives Grower Payment and Available Resource Mix

Feedstock Supply System R&D Plan Contributes:

- Engineering Designs
- Technology Development

$25 Adjusted to 2006 Costs = $32.80

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Feedstock Supply System Models, Business Elements and Interfaces

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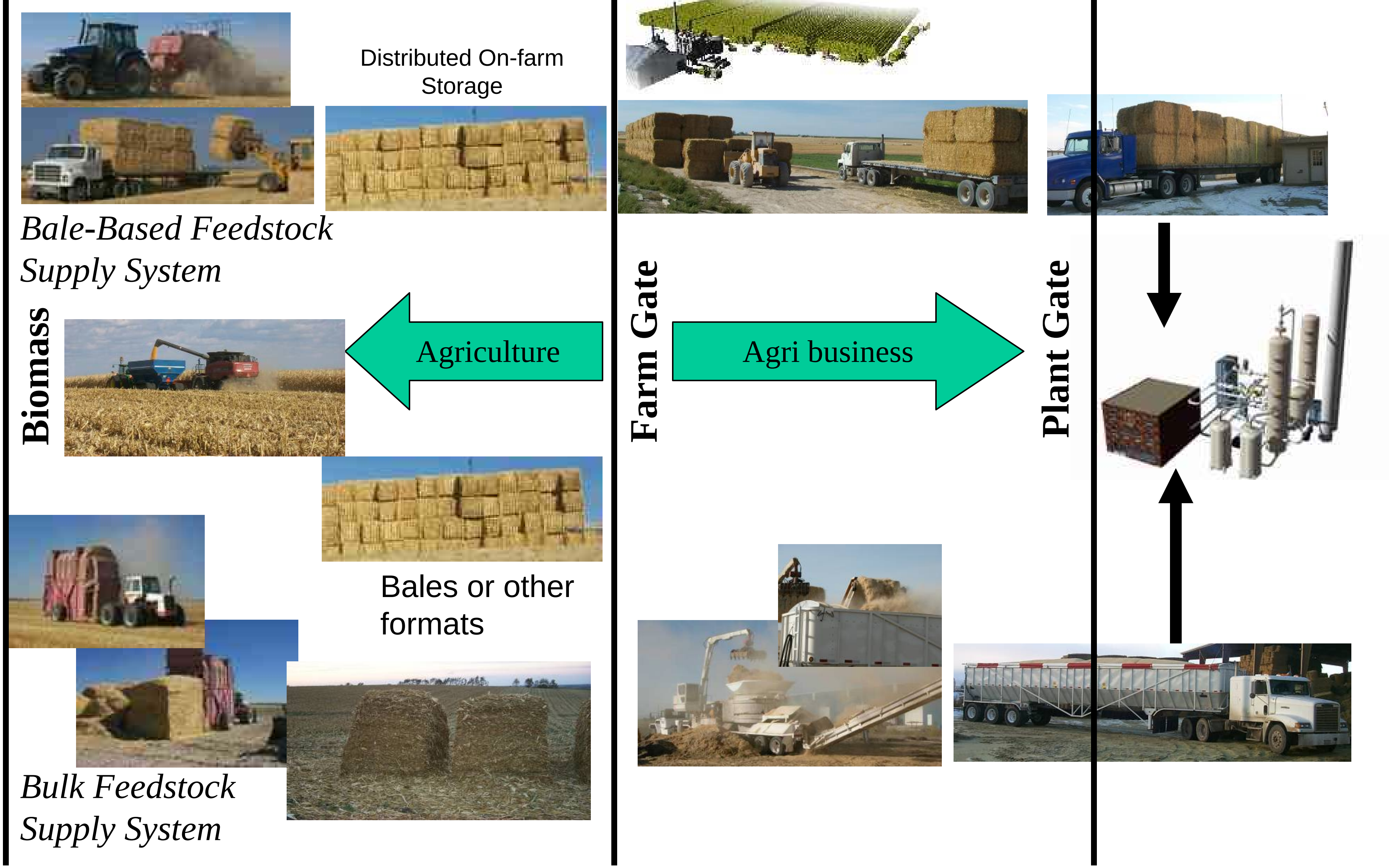
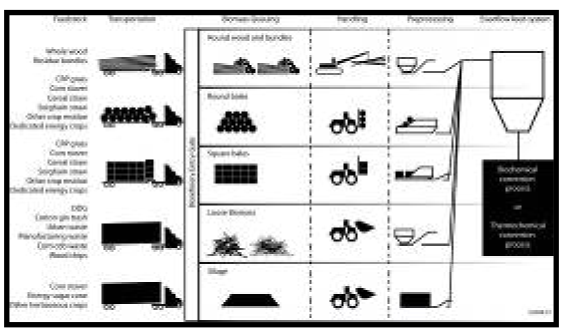


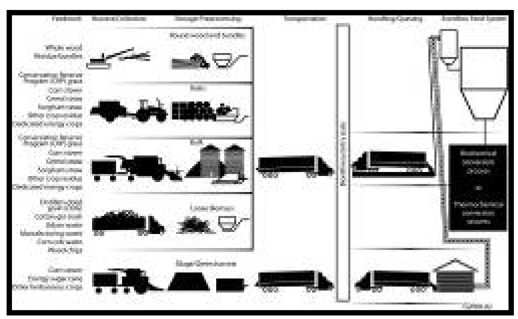
Supply System Design Scenario Summaries (Logistics only)

	Installed Capital Costs ($/dry ton)	Ownership Costs ($/dry ton)	Operating Costs ($/dry ton)	Total Costs ($/dry ton)	Energy Use (Mbtu/dry ton)
Pioneer	$89.13	$13.10	$46.01	$59.11	554.40
Uniform	$111.25	$14.32	$45.19	$59.51	564.30
HD Uniform	$99.08	$11.97	$42.44	$54.41	527.90
Advanced	$46.57	$12.06	$18.61	$30.67	275.62

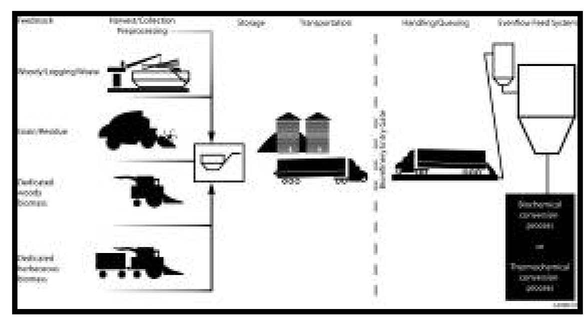
Pioneer



Uniform

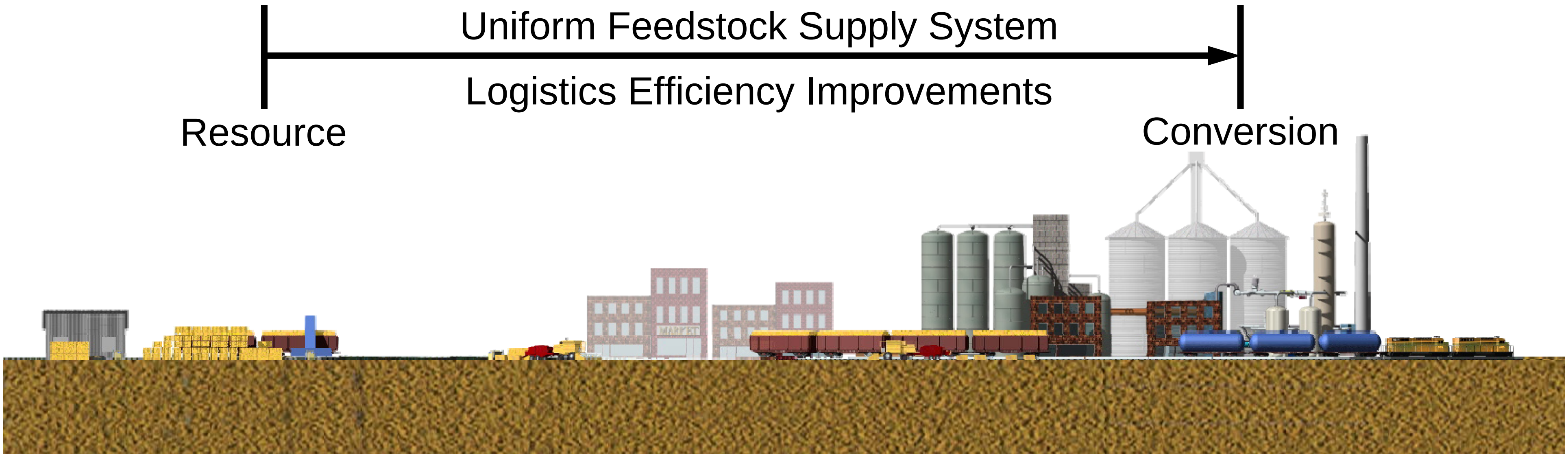


Advanced Uniform

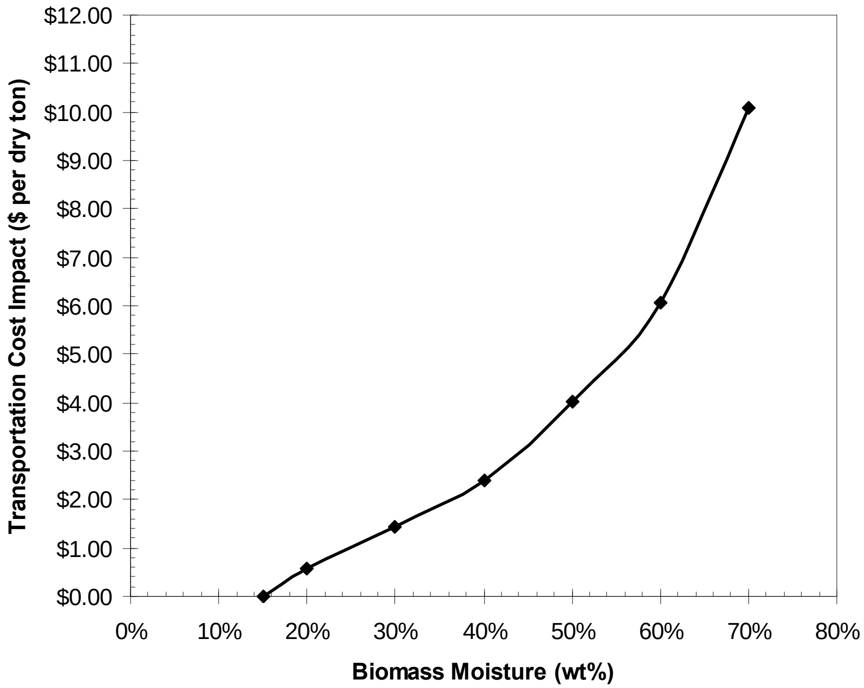


Trends in Feedstock Supply Logistics

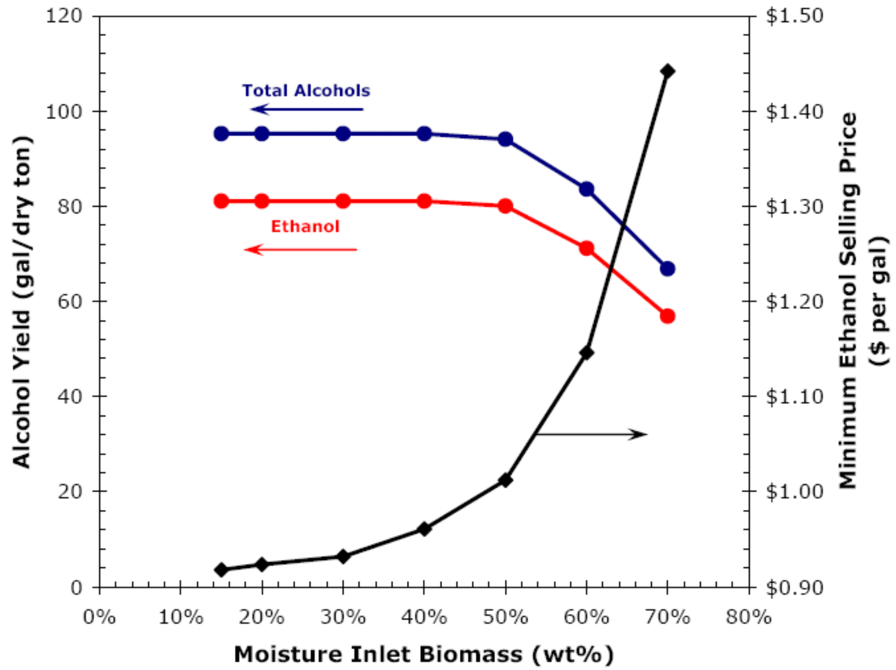
- Connect the Diversity of Feedstock Resources to Standardized Biorefinery Conversion Facilities (Biochem and Thermochem)
  - Standardize biomass material attributes (physical properties) and quality specifications
  - Commodity Scale Lignocellulosic Supply System
- Improve Feedstock Supply System Logistics
  - Engineer (preprocess) biomass materials for more efficient handling/storage
  - Moisture management for stable storage
  - Utilize existing high efficiency solid/liquid handling infrastructure
- Feedstock Crop Development and Sustainable Production



Thermochem Moisture Impact (gasification)



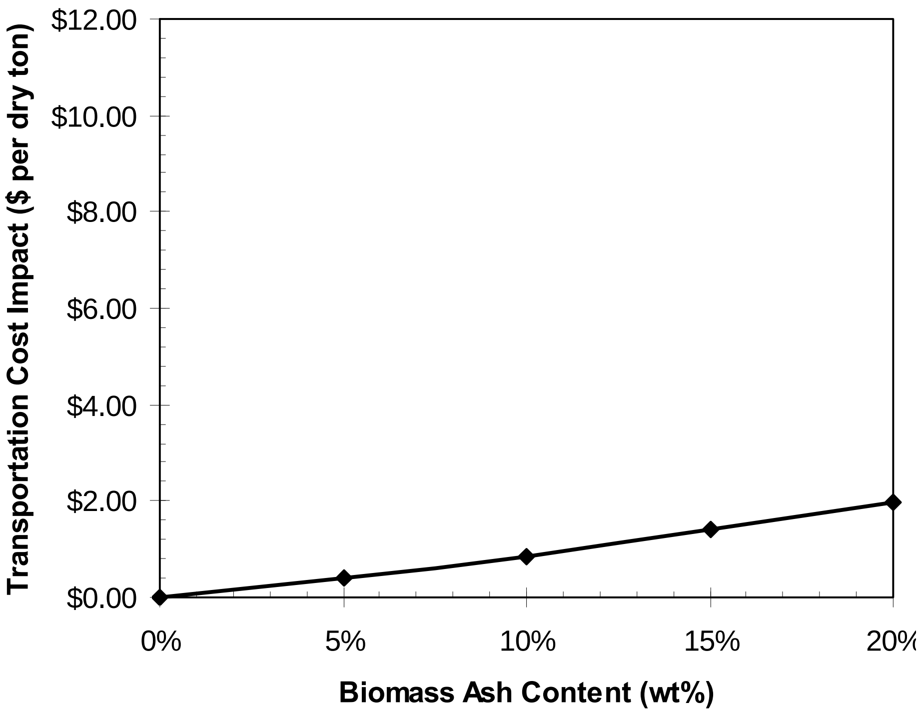
Transportation Cost Sensitivity to Moisture Content
INL Technical Report, In preparation



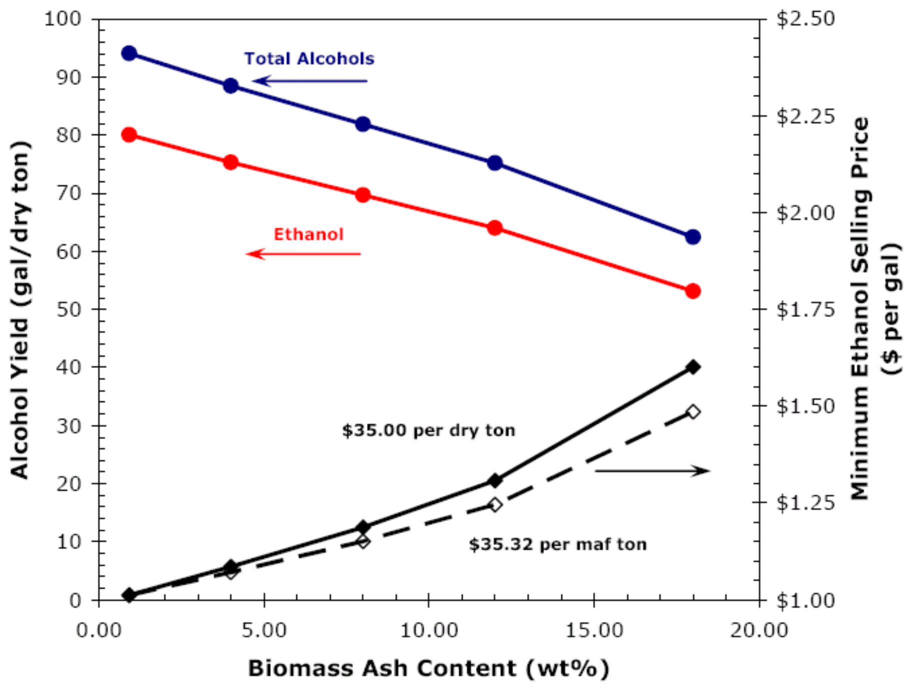
Sensitivity Analysis of Biomass Moisture Content
NREL Technical Report, TP-510-41168

- **Feedstock supply system costs are highly sensitive to biomass moisture content**
- **Thermochemical conversion costs are less sensitive to moisture content**
- **There are multiple mitigation opportunities within the supply system**

Thermochem Ash Content Impact



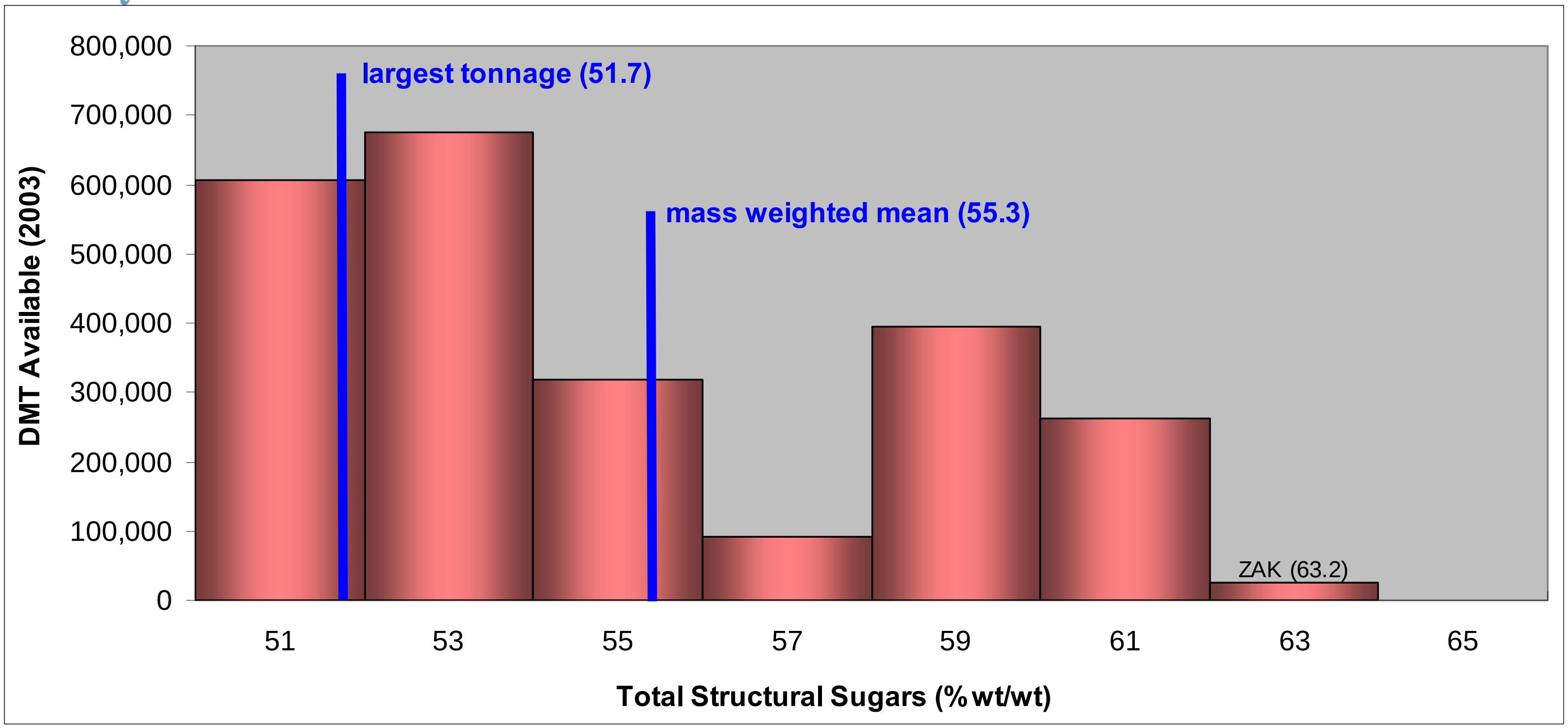
Transportation Cost Sensitivity to Ash Content
INL Technical Report, In preparation



Sensitivity Analysis of Biomass Ash Content
NREL Technical Report, TP-510-41168

- **Conversion costs are highly sensitive to biomass ash content**
- **Feedstock supply system costs are less sensitive to ash content**
- **Ash content is best mitigated within the supply system**

Biochem: Resource Availability by Total Structural Sugar Quality Attributes



MESP ($)	**1.33**	**1.29**	**1.25**	**1.21**	**1.18**	**1.15**	**1.12**	**1.09**
Price ($)	**18.11**	**20.36**	**22.60**	**24.85**	**27.09**	**29.33**	**31.58**	**33.82**

- *Mean and variance marginally useful*
- *Quality factor considerations when choosing biorefinery locations*
- *Impact of biomass quality on grower economics*

Feedstock Supply System Operations

Performance Metrics:
- Efficiency ($/hr)
- Equipment Capacity (ton/hr)
- Biomass Quality ($/ton)

Biomass Production
- Agricultural Resources:
- Forest Resources:

Harvest & Collection → **Storage** → **Preprocessing** → **Transportation** → **Handling & Queuing at the Biorefinery** → | Feedstock Interface Boundary | **Biomass Conversion:**
- Biochemical
- Thermochemical

Harvest & Collection:
- Equipment Capacity
- Compositional Impacts
- Pretreatment Impacts

Storage:
- Shrinkage
- Compositional Impacts
- Pretreatment Impacts
- Soluble Sugar Capture

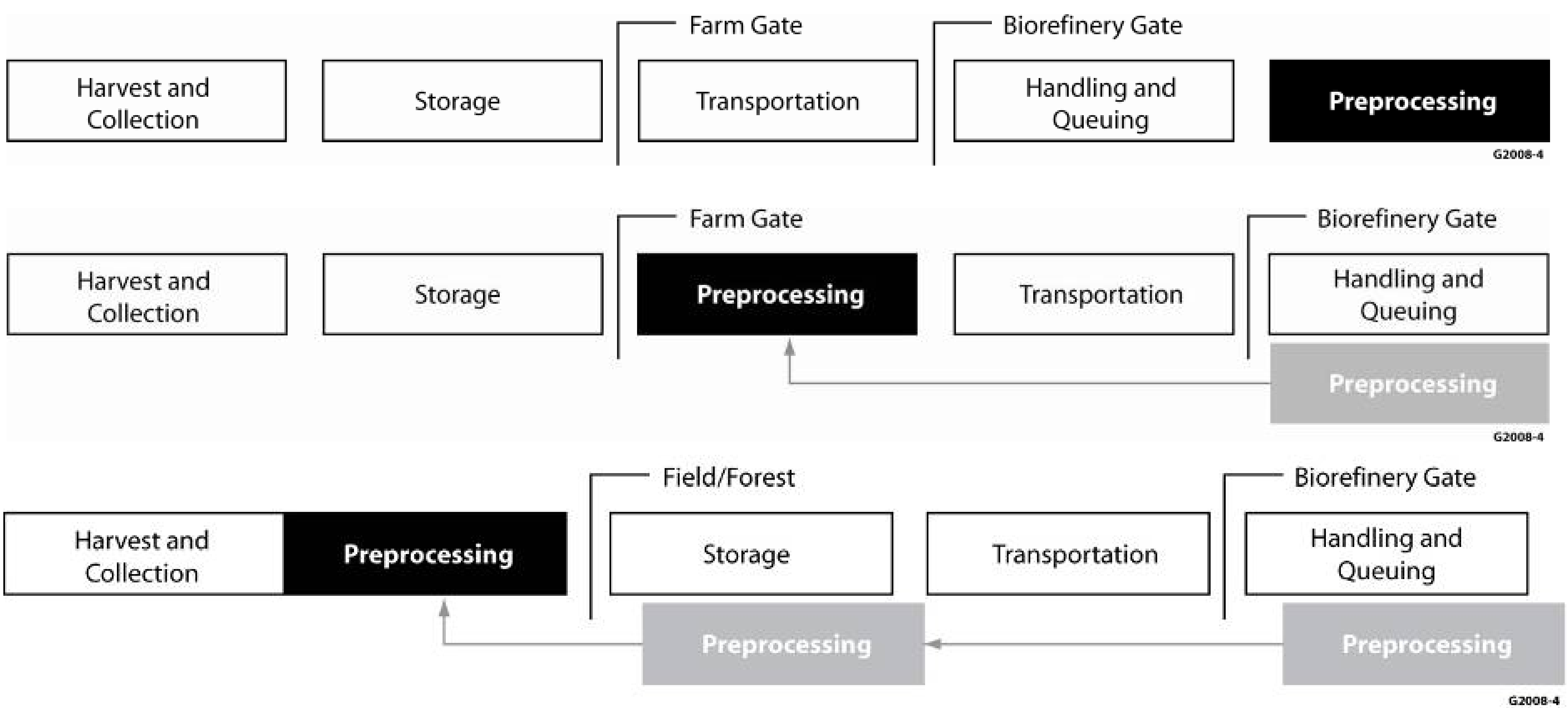
Preprocessing:
- Equipment Capacity
- Equipment Efficiency
- Material Bulk Density
- Compositional Impacts
- Pretreatment Impacts

Transportation:
- Truck Capacity
- Loading compaction
- Loading efficiencies

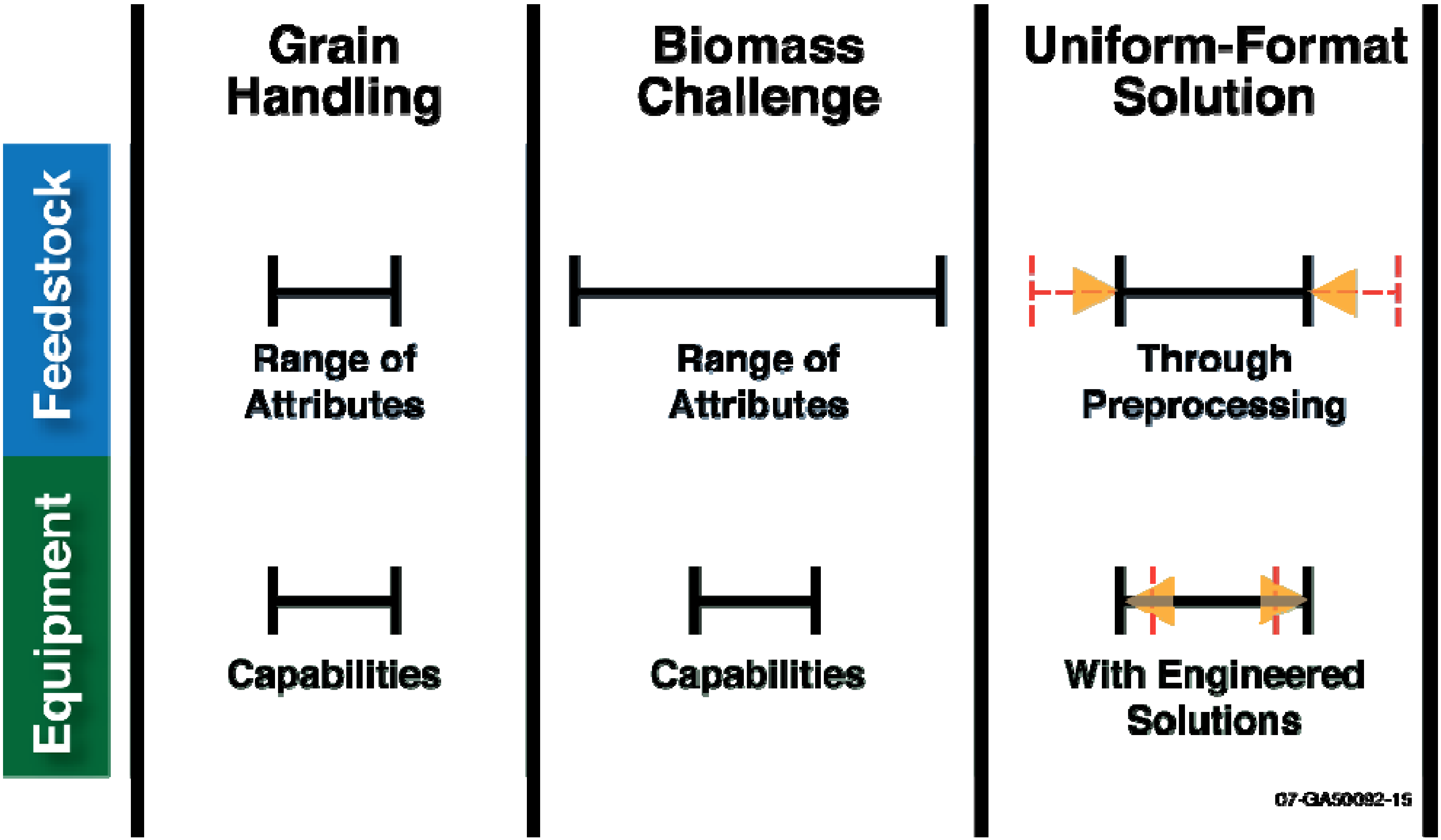
Handling & Queuing at the Biorefinery:
- Handling efficiencies
- Handling compaction
- Material Bulk Properties

R&D Path to the Uniform Feedstock Supply System Design

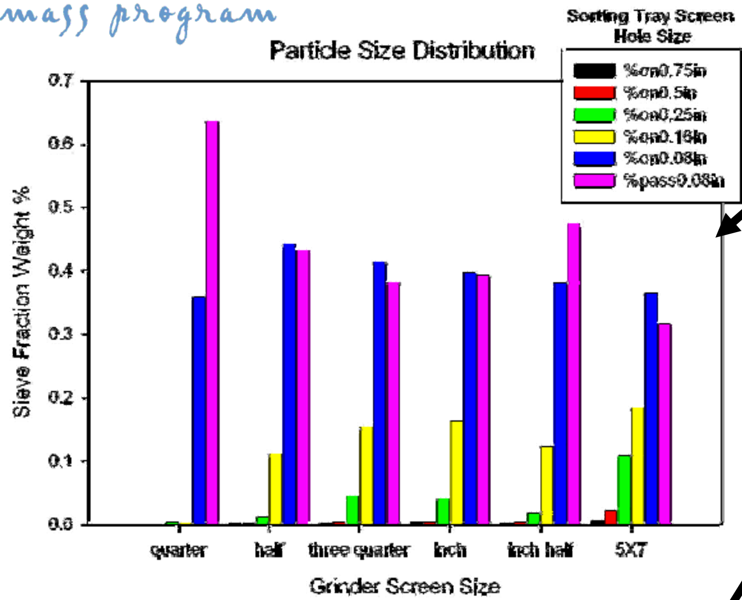
- Harvesting/Collection and Preprocessing are Key Unit Processes
- Harvesting addresses feedstock diversity
- Moving preprocessing forward in the supply system creates down-stream uniformity and increases system efficiencies



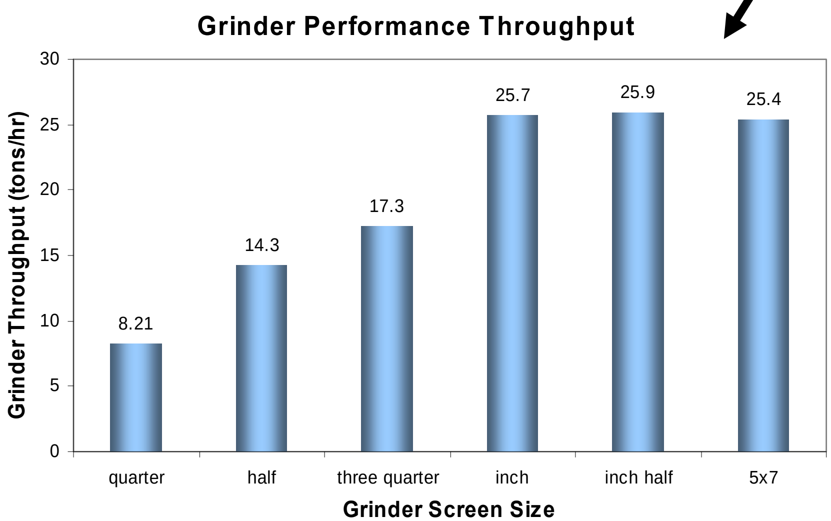
Uniform Format: Alter Feedstock Attributes to Function in Standardized Equipment

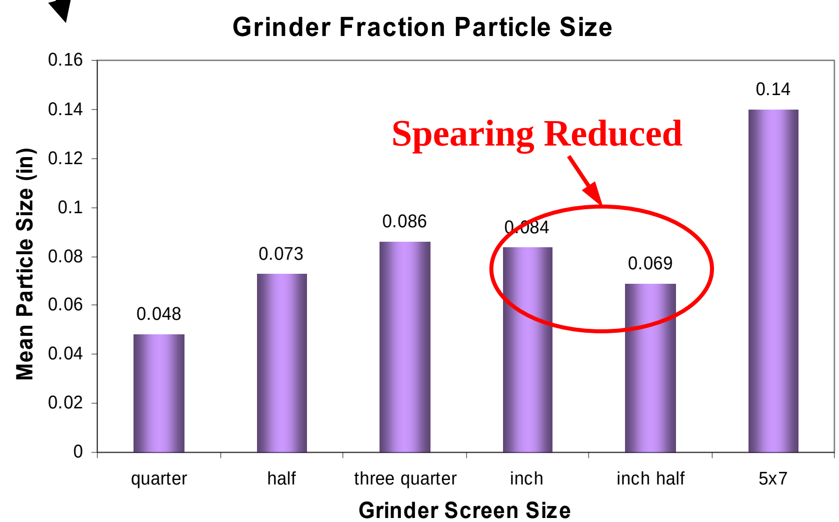


Preprocessing Deconstruction Characteristics



- Different screen sizes cause a differential rate of deconstruction of the material
- Screen geometry directly affects throughput (particle escape) and spearing (loss of size reduction)





Vision Research Phantom 5.1 Video Test

Knife tip speed ~ 8.5 m/sec, Frame rate ~ 10,000 fps

Olympus I-Speed II Video Test

Knife tip speed ~ 8.5 m/sec, Frame rate ~ 5,000 fps

Radiography Tests

- Radiography Techniques show internal structures and potential source of mechanical strength/weakness

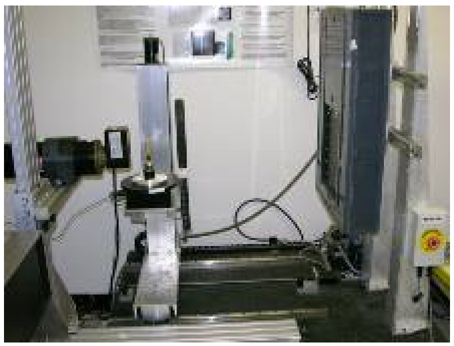
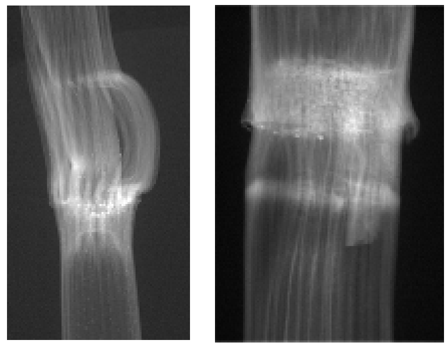
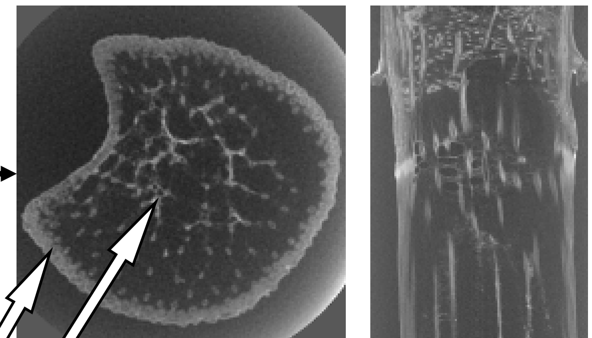


Image Radiography Equipment



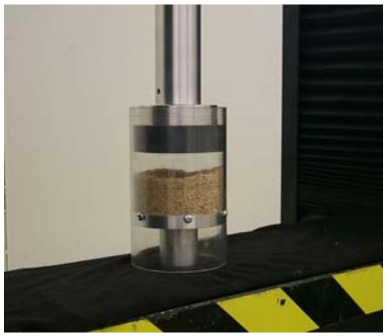
Radiograph projections of barley stover (left) and corn stover (right)



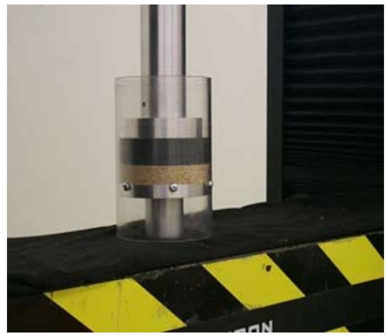
Horizontal and vertical tomographic slices of corn stover.

Un-ground corn stover left in tub

- # Compressibility and Flowability



Compaction

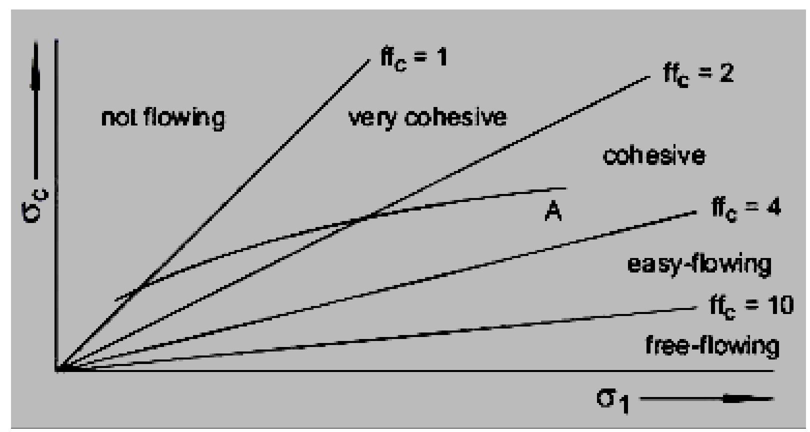


→ **Consolidating Stress**

Shear

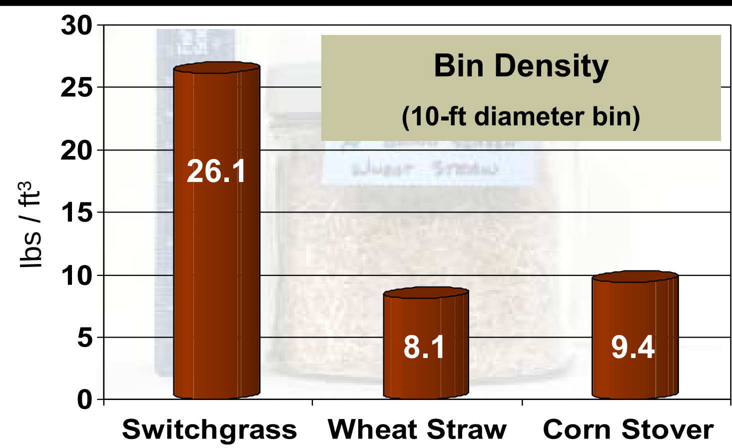
→ **Unconfined Yield Strength**

Flowability Factor (ff_c) = $\dfrac{\text{Consolidating Stress } (\sigma 1)}{\text{Unconfined Yield Strength } (\sigma c)}$

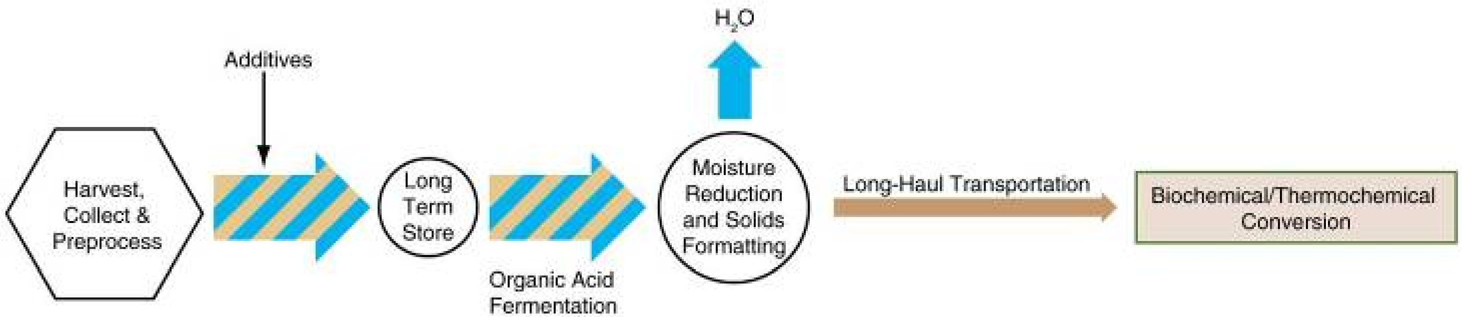


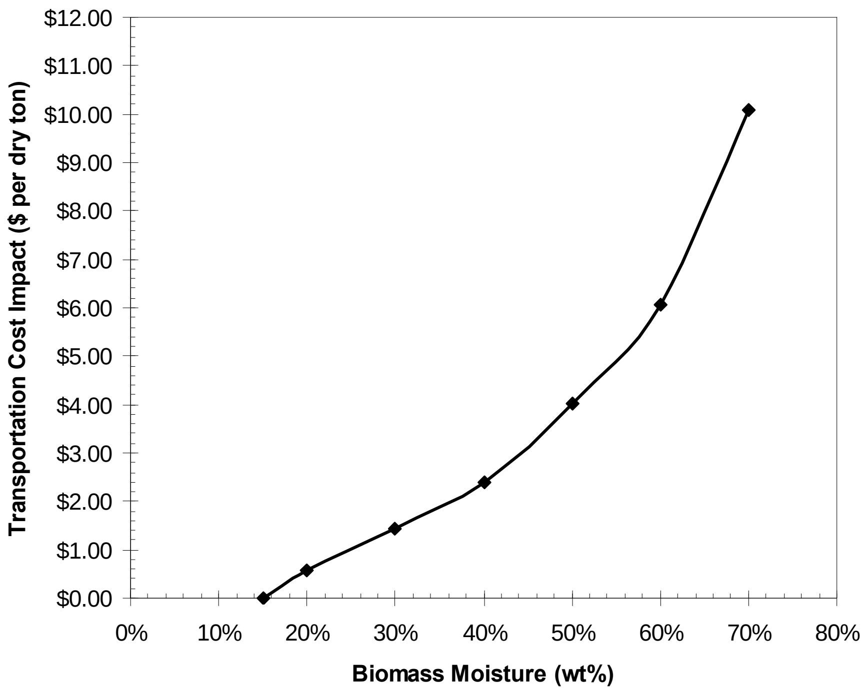
Uniform-Format Preprocessing, Transport, Receiving, & Handling

Feedstock (¼-inch minus)	**Switchgrass**	**Wheat Straw**	**Corn Stover**
Mean Particle Diameter	0.276 mm	0.498 mm	0.346 mm
Particle Size Distribution (wt%)	29.4% > 0.85 mm 0.212 mm < 50.7% < 0.85 mm 18.6% < 0.212 mm	41.6% > 0.85 mm 0.212 mm < 46.9% < 0.85 mm 10.3% < 0.212 mm	24.9% > 0.85 mm 0.212 mm < 56.1% < 0.85 mm 16.9% < 0.212 mm
Bin Density (10-ft diameter bin)	26.1 lbs/ft^3	8.1 lbs/ft^3	9.4 lbs/ft^3
Compressibility (Δ% 0-500 lb/ft^2)	18%	31%	35%
Flowability Factor	5.7 (easily flowing)	1.1 (cohesive)	1.2 (very cohesive)
Permeability	0.27 ft/sec	0.83 ft/sec	0.18 ft/sec
Springback	4.1 %	7.6 %	5.6 %
Angle of Repose	33.6 degrees	35.4 degrees	35.3 degrees



Hybrid Wet / Dry Biomass Feedstock Supply System





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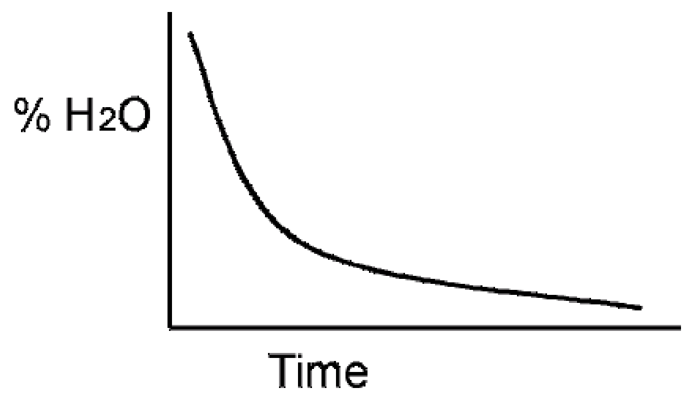
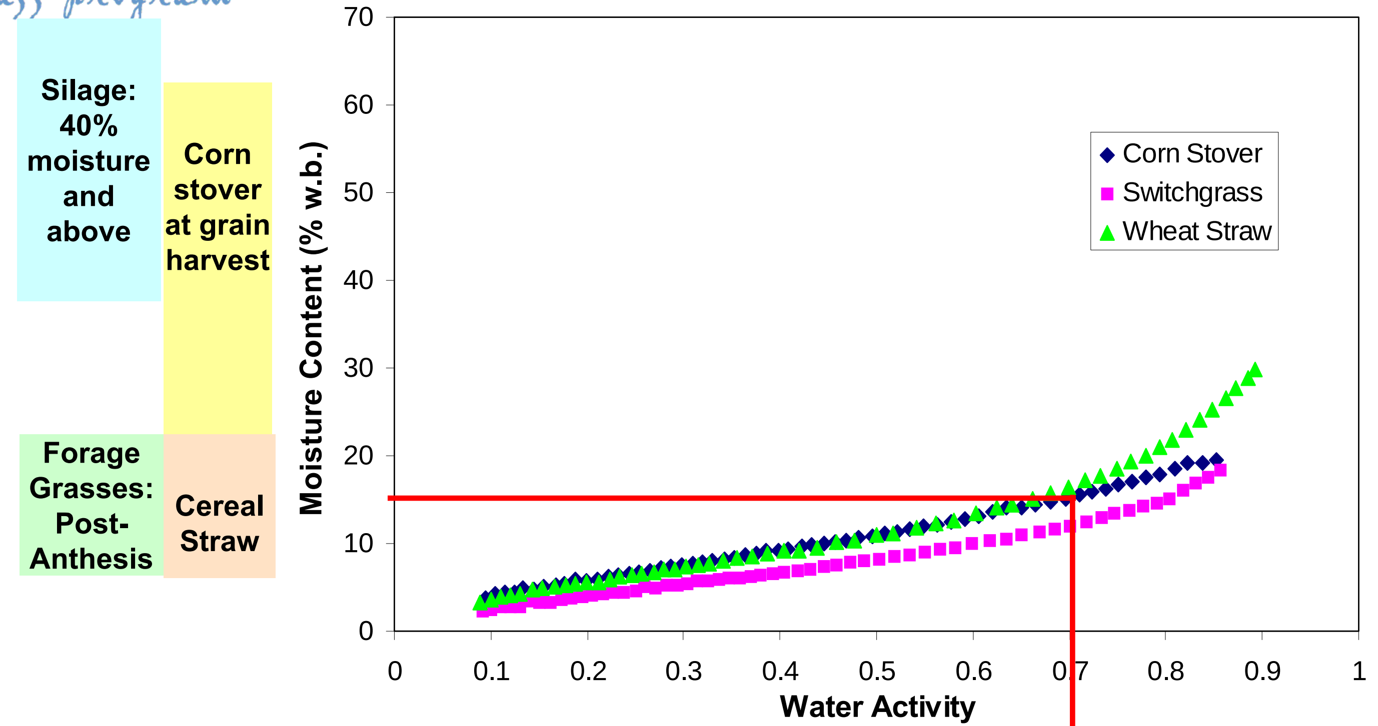


Initial moisture removal (above 25%) requires less energy and time than lower moisture content removal (below 25%)

Water Activity, the key feature for anaerobic and aerobic storage



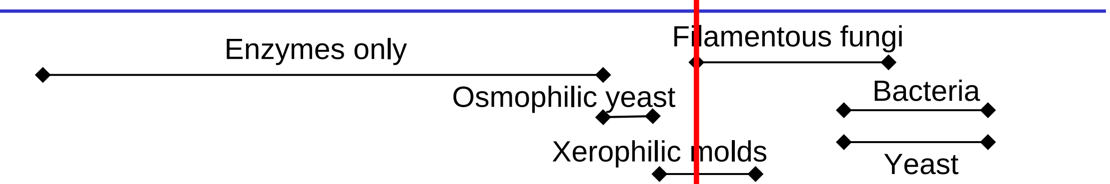
-Rotting at A_w 0.7 suggests moisture limits for dry storage:

Corn Stover: ~ 15%
Switchgrass: ~ 12%
Wheat Straw: ~ 16%

-Opportunity for enzymes

Microbial Activity:

(Beuchat, 1981)



Suggested Storage:

Lignocellulosic Feedstock Types

- Dry Herbaceous – Agriculture Residues/Crops less than 15% moisture
- Wet Herbaceous - Agriculture Residues/Crops greater than about 50% moisture
- Energy Crops – Dry, Wet, and Woody
- Woody – Forest resources and woody energy crops

Supply systems must be tolerant of a diversity of feedstock resources and moisture

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Biorefining Depends on Feedstock