Biomass Feedstock Logistics

Biomass Research & Development Technical Advisory Committee
San Antonio, Texas
February 26, 2009

Richard Hess, Ph.D.
Idaho National Laboratory
• Feedstock Logistics State of Technology
• Uniform Format Supply System Designs to Achieve Cost and Volume (60 Billion gals) Targets
• Technical Work to Achieve Supply System Design Targets – Corn Stover example
  – Regional Feedstock Partnerships for Development of Biomass Resources
  – Logistics
  – Feedstock-Conversion Interface Tasks
Biomass Performance Metrics:
- Physical and Rheological Properties
- Product Bulk Density
- Material Stability

Equipment Performance Metrics:
- Equipment Efficiency / Capacity
- Dry Matter Losses
- Operational Window

Biomass Production
- Agricultural Resources:
- Forest Resources:

Harvest & Collection → Storage → Preprocessing → Transportation → Handling & Queuing at the Biorefinery

Feedstock Interface Boundary

Biomass Conversion:
- Biochemical
- Thermochemical

- Equipment Capacity
- Compositional Impacts
- Pretreatment Impacts

- Truck Capacity
- Loading compaction
- Loading efficiencies

- Handling efficiencies
- Handling compaction
- Material Bulk Properties

- Shrinkage
- Compositional Impacts
- Pretreatment Impacts
- Soluble Sugar Capture
<table>
<thead>
<tr>
<th></th>
<th>Herbaceous</th>
<th>Woody</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Corn Stover</td>
<td>Switchgrass</td>
</tr>
<tr>
<td>2007$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2006 Actual</td>
<td>$57.70</td>
<td>–</td>
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<tr>
<td>2007 Estimate</td>
<td>$54.00</td>
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<td>2007 Actual *</td>
<td>$53.70</td>
<td>$50.80</td>
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<td>2008 Estimate</td>
<td>$49.40</td>
<td>$46.50</td>
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<tr>
<td>2009 Target</td>
<td>$41.60</td>
<td>$41.20</td>
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<tr>
<td>2010 Target</td>
<td>$37.80</td>
<td>$37.20</td>
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<tr>
<td>2011 Target</td>
<td>$36.10</td>
<td>$36.00</td>
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<tr>
<td>2012 Target</td>
<td>$35.00</td>
<td>$35.00</td>
</tr>
<tr>
<td>2017 Target</td>
<td>(\leq 25% \text{ of MESP})</td>
<td>(\leq 25% \text{ of MESP})</td>
</tr>
</tbody>
</table>

* Assume product specification for conventional SOT to be 1/4 to 1/8 minus particle size at 12% moisture.
Feedstock Logistics SOT Estimated Progression to Targets

- Mass Bulk Density (9 → 14 lbs/ft³)
- Grinder Capacity (17 → 22 DM tons/hr)
- Harvest & Collection Efficiency (38% → 50% recovery)
- Material Deconstruction
- Mass & Energy Bulk Density
- Moisture Management
- Equipment Capacity & Efficiency
- Dry Matter Losses
- Operational Window

- Conventional
- Pioneer-Uniform
- Advanced-Uniform


2022, 2025, 2030
Commodities of the Uniform Feedstock Supply System – “Advanced Uniform”

**Bulk Solid Format:**
- High Bulk Density Biomass
- Torrefaction

**Liquid Format:**
- Pyrolysis Oils
- other “Bio-Crude” formats
Uniform Format: Alter Feedstock Attributes to Function in Standardized Equipment

Grain Handling

Biomass Challenge

Uniform-Format Solution

Range of Attributes

Range of Attributes

Through Preprocessing

Capabilities

Capabilities

With Engineered Solutions
A Commodity-Scale Design for Bulk Solid Lignocellulosic Biomass
Basis for the Uniform-Format Design Concept

• A highly efficient, large capacity, dependable feedstock supply system for biomass already exists with the nation’s commodity-scale grain handling and storage infrastructure.

• There is no alternate supply system design for lignocellulosic biomass that could handle the large quantities at the same or greater efficiencies and reliability than the existing grain handling infrastructure.

• The national goal of annually producing 60 billion gallons of ethanol, which requires supplying roughly of 700 million dry matter tons of biomass to a biorefining industry, can only be effectively accomplished through the development of harvesting and preprocessing systems that reformat lignocellulosic biomass resources into a “Uniform-format bulk solid” that can be stored and handled in an expanded grain (i.e., high density aerobically stable bulk solids) commodity infrastructure.
Feedstock Physical Property Challenges:
• Material deconstruction – changes in physical form, rheological characteristics
• Product yield density – biomass format and bulk/energy densities
• Moisture management – aerobic stability, post-harvest physiology, temperature impact

Feedstock Equipment Engineering Challenges:
• Capacity and Operational Efficiency
• Dry Matter Losses (including dust collection/control)
• Operational Window

Interface Challenges:
• Resource Quantities/Sustainability (Feedstock Production)
• Biomass Resources Physical Properties (Feedstock Logistics)
• Biomass Resources Chemical Properties (Biochem and Thermochem)
Feedstock Barriers

Feedstock Physical Property Challenges:
1. Material Deconstruction (physical form/rheological characteristics)
2. Product yield density (biomass format/usable bulk densities)
3. Moisture management (aerobic stability, post-harvest physiology, temperature impact)

Feedstock Equipment Engineering Challenges:
4. Equipment Capacity and Operational Efficiency
5. Dry Matter Losses and Dust Management
6. Operational Window

Conversion Interface Challenges:
7. Resource Quantities (Feedstock Production/Regional Partnerships)
8. Biomass Resources Physical Properties (Feedstock Logistics)
9. Biomass Resources Chemical Properties (Biochem and Thermochem)

Interaction Cycle between Core R&D, Deployable Process Demonstration Units, Industrial Partners, and Demonstration Projects for the Pioneer and Advanced-Uniform Designs

Deployable Process Demonstration Unit (D-PDU)
(Engineering-Scale Uniform Format Development System)
$12 million ($3 M/yr, FY09 – FY12)

Uniform Format Support Laboratories

Pioneer Feedstock Systems Integration and Demonstration
(Industrial Partnership and Solicitation)
Conventional Square Bale Feedstock Supply System

- Same as the Livestock Forage System
- 10 material intermediates, 3 biomass format changes
- 14 process steps, 21 different types of equipment
- Supply system is bale format specific
Switchgrass

Conventional Bale Supply System

Monte Carlo Cost Analysis Results

Frequency

$/dry ton

Total $ / DM...

---

Switchgrass

Minimum: 40.1465
Maximum: 63.2428
Mean: 49.6102
Mode: 49.6238
Std Dev: 3.1982
Values: 10000
Ranking of Factors Influencing Costs in the Conventional Bale Supply System

Bar chart showing the relative impact of various factors on costs. The factors include:
- Bale Bulk Density (lb/ft³) E139
- Field Losses % (Baling) C126
- Moisture (%) C125
- Shredder Capacity (mph) D84
- Baler Capacity (bales/h) F139
- Baler Field Efficiency (%) G139
- Harvest Window N65
- Field Losses % (Harvest) N66
- Shredder Field Efficiency (%) F84
- Transport Winding Factor C210
- Residue Removal Limit (%) C21
- Semi Speed (mph) E224
- Storage Dry Matter Loss (%) G371
- Transport Loader Capacity (bale/h) D235

The chart indicates that Bale Bulk Density has the highest relative impact, followed by Field Losses % (Baling).
Issues:

- Depending on conditions removal rates range from 0% up to 50%
- Yearly production rates can vary significantly
- Because of variability it will be necessary to contract substantially more stover supply than actually needed

* (Perlack et.al, 2007)
Supply is very sensitive to farm gate price

Corn stover national supply curve is very elastic. At low prices the feedstock is largely confined to the corn belt.

Perlack et al, 2008
Oak Ridge National Laboratory
### Agronomic Factors Limiting Crop Potential

<table>
<thead>
<tr>
<th>Limiting factor</th>
<th>Issues</th>
<th>Proposed solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loss of soil organic carbon</td>
<td>Supply/replenish SOC</td>
<td>Restrict stover to maintain SOC</td>
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<tr>
<td></td>
<td>Soil quality</td>
<td></td>
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<td></td>
<td>Future production capacity</td>
<td></td>
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<tr>
<td>Soil erosion</td>
<td>Water erosion and runoff management</td>
<td>Restrict stover to keep soil loss to less than T as indicated by RUSLE2 and WEPS</td>
</tr>
<tr>
<td></td>
<td>Wind erosion management</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Off-site effects</td>
<td></td>
</tr>
<tr>
<td>Loss of plant nutrients</td>
<td>Increased fertilizer application and production costs or reduced crop yield and producer income</td>
<td>Retain stover</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Improve nutrient use efficiency</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Return ligneous by-product or boiler ash to land</td>
</tr>
<tr>
<td>Soil water and temperature dynamics</td>
<td>Complex interactions</td>
<td>Need help here</td>
</tr>
<tr>
<td></td>
<td>Condition-specific solutions necessary</td>
<td></td>
</tr>
<tr>
<td>Soil compaction</td>
<td>Compaction of soil due to increase field traffic for residue removal and/or transition to no-till cropping system</td>
<td>Reduce or eliminate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Use equipment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Conduct field operations</td>
</tr>
<tr>
<td>Environmental degradation</td>
<td>Off-site erosion impacts</td>
<td>Reduce runoff</td>
</tr>
<tr>
<td></td>
<td>Nutrient loss to surface water</td>
<td>Develop alternative measure</td>
</tr>
</tbody>
</table>

- **Spatial Variability of Combine Harvest Index**
  - Data Range 0 (Lower) – 0.75 (Upper)
- **Hard Red Spring Wheat**
- **Ashton, ID - 1996**

Crop Organic Matter return rate recommendations (or biomass input) must be managed just like fertilizers and other crop production inputs.
Regional Biomass Energy Feedstock Partnership 2008 Bioenergy Crop Trials

Total Trials = 38

- CRP
- Energycane
- Switchgrass
- Miscanthus
- Sorghum
- Corn Stover Removal

Planted Field Trials
Planned Field Trials
Organization Location
Core Treatment

- Continuous Corn
- No (or minimum possible) Tillage
- Stover removal treatments of 0%, 50%, maximum possible removal
- Soil sampling protocol
- Management data reporting protocol
- Biomass sampling protocol
Residue Removal Tool Status

Initial Coupling and Data Flow

**Field Plot Historical Data and Agronomic Scenario**
- Residue Composition
- Agronomic
- Soil

**Database Access:**
- NRCS, CLIGEN, etc.
  - Production
  - Weather
  - Soils

**I-FARM User Interface:**
- Scenario Definition / GIS Implementation

**Data Inputs:**
- I-FARM

**Input Datasets**
- Operation
- Crop Production
- Management
- Crop Rotation
- Soils
- Residue Composition
- Weather

**RUSLE2**
- Correlation Based Lookups
- Soil Compaction
- Soil Water and Temperature Dynamics
- Environment Degradation

**CQESTR**

**I-FARM P,K,& N Management**

**Multi-Variant Modeling Framework**

**Residue Removal Analyses**
Residue Removal Tool Status

• Ports on the plugins are then used to connect the components directing the calculation
• Through each of the plugins the scenario definition and computation model specific settings are accessible
• With the system assembled and scenario defined, the network is ready for calculation
Model Integration Status

Erosion
- RUSLE2:
  - Fully integrated and functional utilizing the shared library built at the University of Tennessee.

Soil Organic Carbon
- CQESTR:
  - Fully integrated utilizing a custom built interface class.
  - Model is compiled into an ActiveX executable and integrated using the Microsoft COM API (Common Object Model, and Application Programming Interface).
  - Model code was not altered preserving validation.
  - Finishing work removing the RUSLE1 model dependence.

Nutrient Management
- I-FARM
  - Nutrient cycling functioning within I-FARM analysis framework.

Scenario Setup
- I-FARM
  - Working through remaining server access issues for data sharing, expected to be solved within 1-2 weeks.
- Batch Data Mode
  - Currently functioning ability to setup and run a suite of scenarios through a batch mode.
Demonstration Scenario:

Four Management Treatments

1. Standard Tillage: Chisel Plow, Field Cultivate, Planter Double Disk Opener
2. No Tillage: Planter Double Disk Opener w/ Fluted Coulter
4. No Tillage with Interseeded Legume Cover and Perennial Red Clover Cover: Red Clover regrowth after harvest of corn that has had clover aerially or highboy seeded in growing corn. Covers are chemically killed, mow and bale is possible.

Three Removal Rates per Treatment

1. 0%
2. Approx. 50%
3. Maximum Possible: Approx. 100%

Calculations Performed

• Erosion through RUSLE2
• SOC through CQESTR
Demonstration Scenario:
25 Acre Site near Ames, IA
180 bu/acre average yield

<table>
<thead>
<tr>
<th>Removal Rate</th>
<th>Erosion (T=5.0) (t/acre/yr)</th>
<th>SOC (lbs/acre/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Conv Till</td>
<td>No Till</td>
</tr>
<tr>
<td>0%</td>
<td>0.6</td>
<td>0.061</td>
</tr>
<tr>
<td>50%</td>
<td>2.1</td>
<td>0.21</td>
</tr>
<tr>
<td>100%</td>
<td>2.2</td>
<td>1.1</td>
</tr>
</tbody>
</table>

Outlier currently being reviewed
• Single-pass High cut harvested 72% of stover produced (i.e., 12% more stover collected per acre than billion ton study assumptions), so
• 70% removed with combine
  • Low moisture
  • Reduced pretreatment severity
  • Short soil half-life (Kumar and Goh, 2000; Eiland et al. 2001)
• 30% of stalk left behind
  • High moisture
  • Highly recalcitrant
  • Long soil half-life
• 40% removed with mow and rake – mostly stalk material
Harvest and Collection

- Computational Fluid Dynamics Models (CFD)
- Particle Image Velocimetry (PIV)
- Interactive Design Canvas
- Successful Real-World Application of modified separation chamber
Relative Impact of Biomass Bulk Density on Supply System Unit Operations

Bale Bulk Density (lb/ft$^3$) - Breakout by Process

- **Havest & Collection**: 38.46%
- **Storage**: 29.58%
- **Handling & Transportation**: 29.88%
- **Receiving & Preprocessing**: 2.07%

Less than 5.00%
## Yield and bulk density data for large square bales

<table>
<thead>
<tr>
<th>Crop</th>
<th>Crop Yield (baled DM ton/acre)</th>
<th>DM Bulk Density (lb/ft³)</th>
<th>Bales (4×4×8-ft) /Acre</th>
<th>Bales (3×4×8-ft) /Acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn Stover</td>
<td>1.6</td>
<td>8–9</td>
<td>2.8–3.1</td>
<td>3.7–4.2</td>
</tr>
<tr>
<td>Cereal Straws</td>
<td>1.1</td>
<td>7–9</td>
<td>1.9–2.5</td>
<td>2.6–3.1</td>
</tr>
<tr>
<td>Switchgrass</td>
<td>4.0</td>
<td>11–12</td>
<td>7.0–7.8</td>
<td>9.3–10.4</td>
</tr>
<tr>
<td>Miscanthus</td>
<td>5.1</td>
<td>9–11</td>
<td>8.9–10.0</td>
<td>11.8–13.3</td>
</tr>
</tbody>
</table>

DM Bulk Density Targets (point at which bulk density ceases to be a predominant limiting factor):

- Collection and Transportation = 16 lbs/ft³
- Handling and Storage > 30 lbs/ft³
Material was ground using a commercial tub grinder in the field and separated in various size fractions using a forage separator.
Corn Stover 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
Biomass Differential Deconstruction:

- Pith and other tissues rapidly deconstruct upon impact

- Rind and vascular tissues hold together under impact forces and require shear / torsion forces to effectively size reduce
Video of Operating Grinding Drum – 30 fps
Real-time video of grinding Miscanthus
- 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).
# Differential Properties of Preprocessed Biomass Materials

<table>
<thead>
<tr>
<th>Feedstock (¼-inch minus)</th>
<th>Switchgrass</th>
<th>Wheat Straw</th>
<th>Corn Stover</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Particle Diameter</td>
<td>0.276 mm</td>
<td>0.498 mm</td>
<td>0.346 mm</td>
</tr>
<tr>
<td>Particle Size Distribution (wt%)</td>
<td>29.4% &gt; 0.85 mm</td>
<td>41.6% &gt; 0.85 mm</td>
<td>24.9% &gt; 0.85 mm</td>
</tr>
<tr>
<td></td>
<td>0.212 mm &lt; 50.7% &lt; 0.85 mm</td>
<td>0.212 mm &lt; 46.9% &lt; 0.85 mm</td>
<td>0.212 mm &lt; 56.1% &lt; 0.85 mm</td>
</tr>
<tr>
<td></td>
<td>18.6% &lt; 0.212 mm</td>
<td>10.3% &lt; 0.212 mm</td>
<td>16.9% &lt; 0.212 mm</td>
</tr>
<tr>
<td>Bin Density (10-ft diameter bin)</td>
<td>26.1 lbs/ft³</td>
<td>8.1 lbs/ft³</td>
<td>9.4 lbs/ft³</td>
</tr>
<tr>
<td>Compressibility (Δ% 0-500 lb/ft²)</td>
<td>18%</td>
<td>31%</td>
<td>35%</td>
</tr>
<tr>
<td>Flowability Factor</td>
<td>5.7 (easily flowing)</td>
<td>1.1 (cohesive)</td>
<td>1.2 (very cohesive)</td>
</tr>
<tr>
<td>Permeability</td>
<td>0.27 ft/sec</td>
<td>0.83 ft/sec</td>
<td>0.18 ft/sec</td>
</tr>
<tr>
<td>Springback</td>
<td>4.1 %</td>
<td>7.6 %</td>
<td>5.6 %</td>
</tr>
<tr>
<td>Angle of Repose</td>
<td>33.6 degrees</td>
<td>35.4 degrees</td>
<td>35.3 degrees</td>
</tr>
</tbody>
</table>

## Bin Density (10-ft diameter bin)

- Switchgrass: 26.1 lbs/ft³
- Wheat Straw: 8.1 lbs/ft³
- Corn Stover: 9.4 lbs/ft³
Wet versus Dry Biomass Effects

Moisture Content (% w.b.) vs Water Activity

- Corn Stover
- Switchgrass
- Wheat Straw

Microbial Activity: (Beuchat, 1981)
- Enzymes only
- Osmophilic Yeast
- Xerophilic molds
- Filamentous Fungi
- Bacteria
- Yeast

Suggested Storage:
- Dry Storage
- Wet Storage
R&D Details:
- Assess soluble sugar capture systems
- Expand wet design concepts for $35 target
- Assess performance of key storage systems
- Investigate function / composition tradeoffs (i.e., can we stabilize & destabilize together?)
- Extend dry systems for use in wet climates
Opportunities for Quality Changes

Harvesting
• Use single pass harvesting to minimize contamination
• Selective harvest
  - Plant fractions with varying compositional qualities
• Schedule harvest
  - minimize moisture content
  - alter mineral content
  - lignin to cellulose ratio

Preprocessing
• Grind to smaller particle sizes to increase bulk density
• Alter particle shape factors
• Selectively screen and separate to increase quality

Storage/Queuing
• Reduce dry material losses
• Apply pretreatments to impact physical properties
• Leach out contaminate
<table>
<thead>
<tr>
<th>Attributes</th>
<th>Conversion System Impact</th>
<th>Assembly System Impact</th>
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</thead>
<tbody>
<tr>
<td>Physical Properties</td>
<td>Heat and mass transfer, Energy balance, Product composition</td>
<td>Grinding Efficiency, Transportation economics, Feeding and Handling Efficiency, Storage Stability</td>
</tr>
<tr>
<td>Moisture</td>
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<tr>
<td>Particle Size</td>
<td>Feeding and entrainment, Solids loading</td>
<td>Grinding Efficiency, Storage capacity</td>
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<tr>
<td>Shape</td>
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<tr>
<td>Density</td>
<td>Heat and Mass Transfer, Reactivity</td>
<td>Feeding and Handling Efficiency</td>
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<tr>
<td>Porosity</td>
<td>Acid pretreatment</td>
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<td>Permeability</td>
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<td>Thermal Conductivity</td>
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<td>Heat Capacity</td>
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<td>Assembly System Impact</td>
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<tr>
<td><strong>Chemical Properties</strong></td>
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<tr>
<td>Fixed Carbon</td>
<td>Reactivity</td>
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<tr>
<td>Volatile Matter</td>
<td>Product yield</td>
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<tr>
<td>O:C ratio</td>
<td>Energy Content</td>
<td></td>
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<tr>
<td>H:C ratio</td>
<td>Tar Formation</td>
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<tr>
<td>Cellulose:lignin</td>
<td>Ethanol yield</td>
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<tr>
<td>N</td>
<td>NO(_x) Production</td>
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<tr>
<td>S</td>
<td>Fuel Quality, Catalysis activity, Lifetime</td>
<td></td>
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<tr>
<td>Cl</td>
<td>Facilitates Ash Formation, Corrosion</td>
<td></td>
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<tr>
<td>Ash</td>
<td>Lowers Energy Density</td>
<td>Equipment Wear</td>
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<td>Si</td>
<td>Acid treatment buffering</td>
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<td>Na</td>
<td>System Fouling</td>
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<td>K</td>
<td>Ash Softening</td>
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<td>Mg</td>
<td>Corrosion, Erosion</td>
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<td>P</td>
<td>Catalytic properties</td>
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<tr>
<td>Ca</td>
<td>Decomposition Temperature</td>
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<td>Fe</td>
<td>Influences Product Distribution</td>
<td></td>
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<tr>
<td></td>
<td>and Yield</td>
<td></td>
</tr>
</tbody>
</table>
• Average chemical composition

• Variability of composition
• The process of size reduction does not randomly reduce all the different components of biomass materials in a uniform manner
  
  – Different size fractions may differ significantly in their chemical properties
  
  • partial separation of inorganic and organic matter
## Preprocessing Impact on Feedstock Biochemical Quality

<table>
<thead>
<tr>
<th>Grinder Screen 2-inch</th>
<th>GLUCAN (%)</th>
<th>Xylan (%)</th>
<th>GALACTAN (%)</th>
<th>ARABINAN (%)</th>
<th>Total Sugars</th>
<th>MES</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Screen</td>
<td>36.57</td>
<td>16.68</td>
<td>0.91</td>
<td>1.70</td>
<td>55.86</td>
<td>1.25</td>
</tr>
<tr>
<td>Tray 2</td>
<td>39.74</td>
<td>16.77</td>
<td>0.78</td>
<td>1.36</td>
<td>58.65</td>
<td>1.19</td>
</tr>
<tr>
<td>Tray 3</td>
<td>39.08</td>
<td>16.98</td>
<td>0.79</td>
<td>1.44</td>
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<td>1.82</td>
<td>1.80</td>
<td>37.94</td>
<td>1.80</td>
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</table>

*Pan images show various types of plant material.*

*Note: MES stands for Mass Emissions Score.*

*ARABINAN, GLUCAN, XYLAN, GALACTAN are biochemical components commonly found in feedstock.*

*Total Sugars are calculated as the sum of GLUCAN, Xylan, GALACTAN, and ARABINAN percentages.*
### Preprocessing Impact on Feedstock Thermochemical Quality

<table>
<thead>
<tr>
<th></th>
<th>No Screen</th>
<th>Tray 3</th>
<th>Tray 4</th>
<th>Tray 5</th>
<th>Tray 6</th>
<th>Pan</th>
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<td><strong>Proximate Analysis (% dry fuel)</strong></td>
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<td>Fixed C</td>
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<td><strong>Ultimate Analysis (% dry fuel)</strong></td>
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<td>5.72</td>
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<td>O (Diff.)</td>
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<td><strong>Elemental Composition of Ash (%)</strong></td>
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</table>
• Feedstock supply system is most sensitive to physical property attributes
  – Moisture
  – Bulk density

• Conversion systems are most sensitive to compositional attributes
  – Carbohydrate
  – Lignin
  – Ash

• Conversion systems may also be sensitive to physical properties, depending upon process design
  – Moisture
  – Particle size and size distribution
Overall Assessment for Corn Stover

- Corn stover removal causes real issues with sustainable agricultural practices, but prescriptive removal tools and selective harvest technologies can address these issues.
- Initially, new corn stover biorefineries will operate with conventional (dry) forage supply systems or employ corn cob only technologies.
- Baled-based systems (i.e., conventional forage technologies) cannot simultaneously meet:
  - 2012 and beyond cost targets (< $32.80 per dry ton)
  - 2030 tonnage targets (600-700 million dry tons annually)
- Lignocellulosic biomass supply systems must be developed into commodity-scale systems based on advanced uniform formats. Corn cob system represent a 1st generation implementation of such.
- Densification and moisture management is key to performance.
- Harvest and supply system losses must be minimized.
- Single pass harvest methods will improve system performance.
Recommendations for Corn Stover

1st Generation Pioneer Systems
• Selective Harvest/Prescriptive removal address sustainability
• Dry Feedstock System
• Locate in dry high productive Corn Belt Region (north/west regions)
• Square Bale with conventional equipment
• Corn Cob only supply systems for wetter or sustainably sensitive regions

Advance-Uniform Supply System
• Cover Crops, Energy Crops, and Improved Corn Crop Genetics solve sustainability issues
• Single Pass Harvester
• Multiple Resources (e.g., corn stover and energy crops together)
• Active moisture mitigation/material stabilization
• Material Bulk and Energy Densification
• Commodity-Scale Solid and/or Liquid based supply systems
Collectively, many biomass preprocessing depots produce infrastructure compatible lignocellulosic intermediates at a commodity-scale.

**Biomass Resources**
- Grains
- Round Wood

**Process Intermediates**
- Vegetable Oils
- Bio-oil/Crude
- High Density Stable Bulk Solid Biomass

**Bioenergy Products**
- Bio-Liquid Fuels
- Bio-Power
- Bio-Chemicals
- Bio-Gas
Biorefining Depends on Feedstock