Feedstock Logistics Systems for a Large Square Bale Corn Stover Supply Chain

Dr. Matt Darr
Agricultural and Biosystems Engineering
Bioeconomy Institute
Iowa State University

Prepared for USDA Teleseminar on Feedstock Logistics
June 21st 2011
Iowa State Biomass Feedstock Supply Experience

- Research partner for corn stover harvest on nearly 8,000 acres over the past 4 years.
- Combined expertise in all areas of harvest, storage, and transportation as well as geographic supply modeling and variable rate harvesting.
- Co-located with biochemical and thermochemical conversion researchers.
Corn Stover Supply Chain

Production Activities

Feedstock Development → Biomass Harvest → Collection Logistics → Biomass Storage → Delivery Logistics

Feedstock Receiving & Staging → Feedstock Preparation → Biomass Conversion

Plant Activities
Supply Chain Areas of Focus

- Available harvesting window for corn stover.
- Impact of bale format on supply chain capacity.
- Long term solutions for feedstock storage.
- Understanding quality metrics and setting reasonable targets.
Biorefinery Requirements

• 25 MMGY cellulosic ethanol plant will require 335,000 tons of biomass per year.
  – Approximately 670,000 large bales of corn stover per year.

• Biorefineries desire uniform feedstock with “low” ash content and “low” moisture content.
Impact of Harvest Window

Typical large square baler can produce 16 ton/hr of biomass.
Iowa Corn Harvest Timeline

Timeline of Iowa Corn Harvest Progress (%)

Day of Year

Year

- 1995
- 1996
- 1997
- 1998
- 1999
- 2000
- 2001
- 2002
- 2003
- 2004
- 2005
- 2006
- 2007
- 2008
- 2009
- 2010
Iowa Harvest Rate from 1999 - 2010

Harvest % = 1 - \( \exp(-5.98018 \times 10^{-6} \times \text{Harvest Days}^3.36817) \)

70% of Iowa corn will be harvested within a 22 day window.

Late corn will have poor field conditions.

Early corn will contain higher moisture, but may be able to field dry.
Baler Productivity

Influence of Harvest Duration on Yearly Baler Yield

Days of Available Harvest vs. Seasonal LSB Bale Yield

Operating Hours:
- 8 hours (black line)
- 10 hours (red line)
- 12 hours (green line)
- 14 hours (blue line)
- 16 hours (orange line)

The graph illustrates the relationship between the number of days of available harvest and the corresponding seasonal LSB bale yield, under different operating hours.
Influences of Bale Format on Supply Chain

- Capital costs for harvesting
- Intermediate stacking and loading costs
- Transportation costs
- Safety
- Feedstock quality
- Processing costs
- Uniformity
- Storage
- Traceability
Capital Costs for Baling Equipment

- **6 ft diameter round baler.**
  - $45 – 55k
- Well suited for producer owned model.

- **3 ft x 4 ft large square baler.**
  - $125 – 140k
- Well suited for custom operator model.

Photo Courtesy of: Vermeer
Bale Collection

- Wide variety available with capacity ranges from 6 to 18 bales.

- Towed and self propelled options with normal ranges from 6 to 12 bales.
Round Bale Handling
Large Square Bale Handling

Truck loading time is proportional to the number of loading cycles.
Round Bales – 1 or 2 bales;  Telehandler LSB – 3 bales;
Squeeze LSB – 6 or 9 bales
Bale Stacking
Bale Stacking

Round bales only utilize 50% of the stacking capacity when compared to square bales. This indicates that round bales need twice the storage area.
Bale Transportation
Bale Uniformity and Durability
### Bale Format Comparisons

<table>
<thead>
<tr>
<th></th>
<th>Baling Cost</th>
<th>Bale Collection</th>
<th>Bale Handling</th>
<th>Bale Stacking</th>
<th>Bale Transport</th>
<th>Bale Uniformity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Square</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Round</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Single Pass Baling Systems
Advantages of Single Pass Baling

Multi-pass Harvesting Platform
- Grain Harvest
- Windrowing
- Baling
- Corn Stover Bale

Single-pass Harvesting Platform
- Mature Corn
- Dual Stream Harvest
Single Pass Baling

• Advantages:
  – Extremely clean biomass product.
  – Lower moisture content than typical bales.
  – Enables variable rate collection.
  – Transitions in-field logistics into only a collection operation which reduces risk and cost during short harvest interval.

• Disadvantages:
  – Towing the baler reduces the combine productivity by 11%.
  – Additional combine development is required to increase stover collection at the head and improved efficiency in processing stover.
  – Lower utilization of the baler increases baling costs.
Biomass Storage Systems

Ensiled Wet Storage

Field Edge Storage

Satellite Storage

Hoop Storage
Ranking Factors for Storage Systems

- **Feedstock Stability**
  - Measured by dry matter loss

- **Infrastructure Investment**
  - Measured by per ton cost

- **Accessibility**
  - Measured by period of available use

- **Supply Chain Integration**
  - Measured by influence on alternative supply chain systems
Wrapped Anaerobic Bale Storage

• **Feedstock Stability**
  – 2 – 5% DML for bales with initial MC between 20 – 30%

• **Infrastructure Investment**
  – Low capital cost.
  – Material and labor cost approximately $9/ton.

• **Accessibility**
  – Format lends itself to field edge stacks which are not widely accessible.

• **Supply Chain Integration**
  – Requires disposal of wrapping material and does increase the moisture content of the feedstock.
Field Edge Storage

- **Feedstock Stability**
  - 6 – 8% DML for bales with initial MC less than 18%

- **Infrastructure Investment**
  - Low capital cost and material cost.

- **Accessibility**
  - Not widely accessible during winter months and wet periods.
  - May require removal before spring.

- **Supply Chain Integration**
  - Eliminates intermediate transportation step at harvest which is a significant advantage and distributes storage risk.
Satellite Storage

- **Feedstock Stability**
  - 6 – 8% DML for bales with initial MC less than 18%

- **Infrastructure Investment**
  - Higher capital cost than field edge storage, but still low material cost.

- **Accessibility**
  - Year round accessibility.

- **Supply Chain Integration**
  - Required high capacity transportation during short harvest period.
  - Provides simpler inventory management and quality control.
Hoop Building Storage

- **Feedstock Stability**
  - 1 – 3% DML for bales with initial MC less than 18%

- **Infrastructure Investment**
  - High capital cost. Approximately $10/ft$^2$ installed.

- **Accessibility**
  - Year round accessibility.

- **Supply Chain Integration**
  - Required high capacity transportation during short harvest period.
  - Provides simpler inventory management and quality control.
  - Excellent feedstock quality.
# Comparing Storage Systems

<table>
<thead>
<tr>
<th></th>
<th>Stability</th>
<th>Cost</th>
<th>Access</th>
<th>Integration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wrapped</td>
<td>+</td>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Field Edge</td>
<td>0</td>
<td>+</td>
<td>-</td>
<td>O</td>
</tr>
<tr>
<td>Satellite</td>
<td>0</td>
<td>0</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Hoop Barn</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>
Biomass Quality Control

- Moisture Content
- Ash Content
- Compositional Quality
- Nutrient Removal
What is Ash?

• Ash is any non-combustible material included in the biomass feedstock.

• Ash in corn stover comes mainly from soil contamination.
Typical Estimates and Ranges of Ash Values

• Published values for ash range from 8% to 25%.
• High variability exists within windrow treatments.
• Ash content increases as aggressiveness of windrowing treatments increase.

Ash Sample with 20% Soil Contamination
Alternative Sources of Ash

• Ash can also be collected from:
  – Sliding bales during collection
  – Rocks on storage surface
  – Root balls engaged during baling
  – Miscellaneous rock and debris

With training and management, soil and foreign matter contamination can be reduced. Ash is much more controllable than moisture or compositional content.
Improved Quality Control Harvesting Systems

- Single pass harvesting consistently produces bales with ash content between 3.2 – 4.2%.
- 50% of this ash is internal to the plant and the remaining ash is associated with soil contamination on the plant at harvest.
Configuring the Corn Stover Supply Chain

**Feedstock Development**

**Biomass Harvest**

**Collection Logistics**

**Biomass Storage**

**Delivery Logistics**

Year Round

22 – 25 Days

Year Round
Keys to Supplying 670,000 LSB per Year

• Know the system limits and operate at the edge of the limitation.
  – Limits may be biologically, environmentally, or economically driven.
• Educate operators on feedstock quality to minimize contamination of biomass.
• Operate in high density and high yielding areas. Machine and operational efficiencies increase with harvest rates.
• Standardize the densification format across the supply chain to maximize equipment utilization.
• Diversify storage systems to simplify at harvest activities and aggressively seek out options for storage locations.
  – Maintain sufficient industrial storage to supply the plant during harsh weather periods.
  – Leverage in-field storage to maximize machinery capacity.
  – Utilize ensiled storage for early harvest period.
Gaps in Large Scale Corn Stover Supply Chains

• Lack of a viable system for traceability of feedstock physical properties and inventory information.
• Poor understanding of driving factors which induce soil contamination in the corn stover production process.
• Highly variable feedstock will require new techniques for rapid analysis at the biorefinery gate.
• Without incentive programs the commercial value of corn stover will cause challenges in increasing producer participation which is a key driver in supply chain costs.
• What comes first the Biorefinery or the Supply Chain?
  – And can the supply chain keep pace with biorefinery development?
Acknowledgements

• Faculty Collaborators:
  – Dr. Stuart Birrell, Dr. Robert Brown, & Dr. Rob Anex

• Graduate Students:
  – Jeremy Brue, Kevin Peyton, Dorde Medic, Brittany Schon, Ajay Shah, Curt Thoreson, Keith Webster

• Research Sponsors and Partners:
  – ADM, AGCO, Avello Bioenergy, ConocoPhillips, DuPont Danisco Cellulosic Ethanol, Hawkeye Renewables, John Deere, North Central Sun Grant, Pioneer, PowerStock, & Toyota
Questions