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

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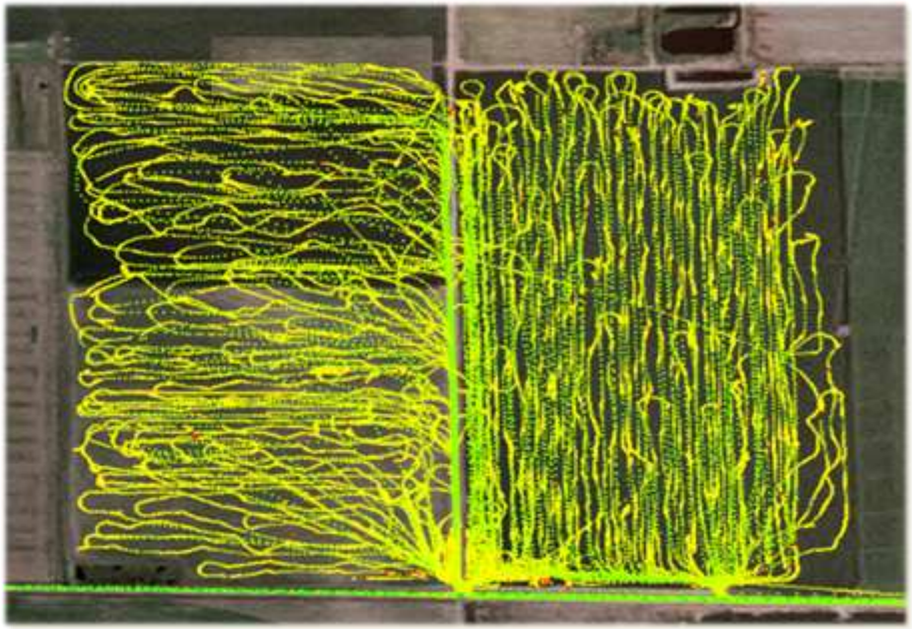
# Iowa State Biomass Feedstock Supply Experience

- 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.



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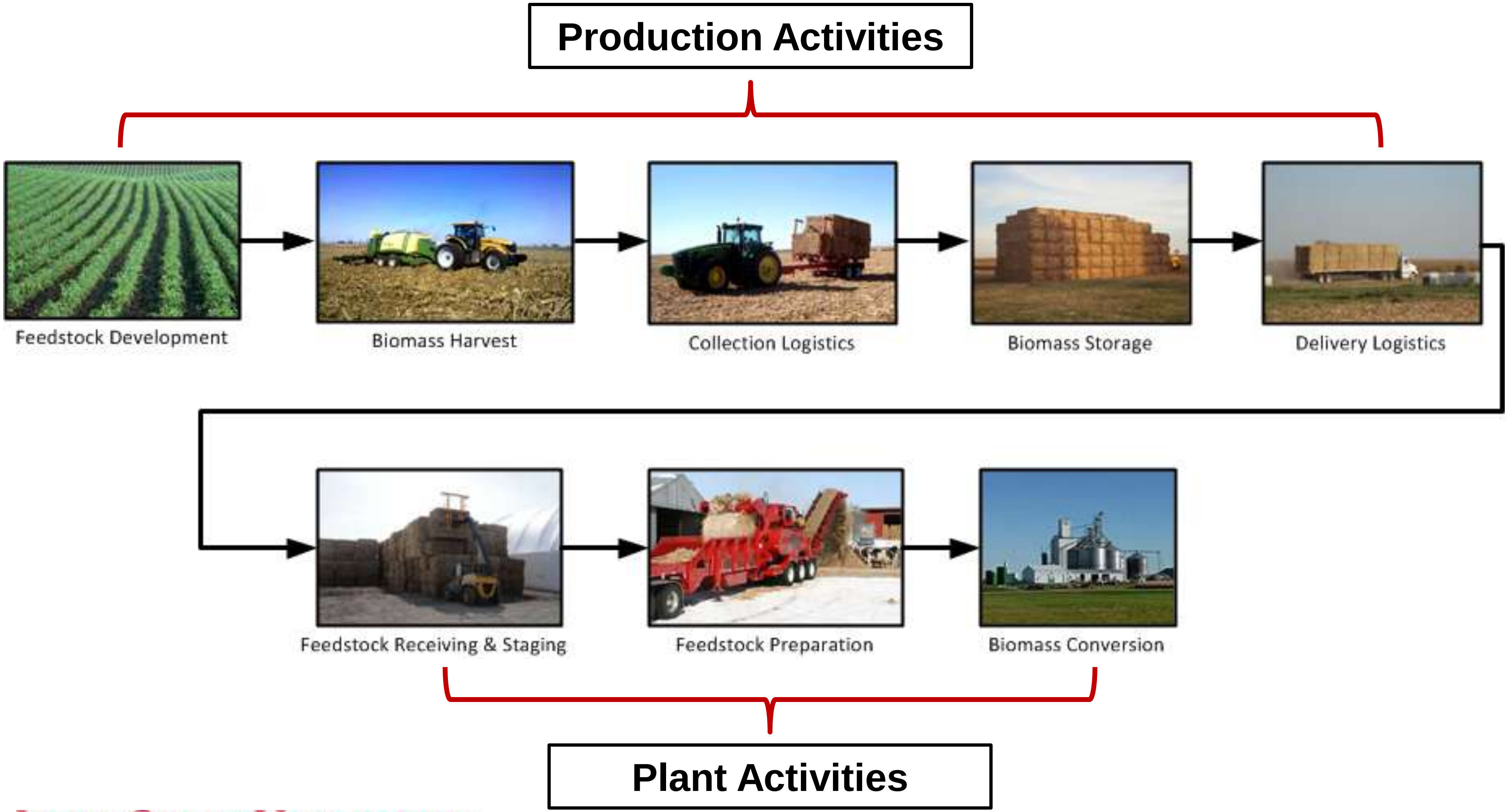
# Corn Stover Supply Chain



# Supply Chain Areas of Focus

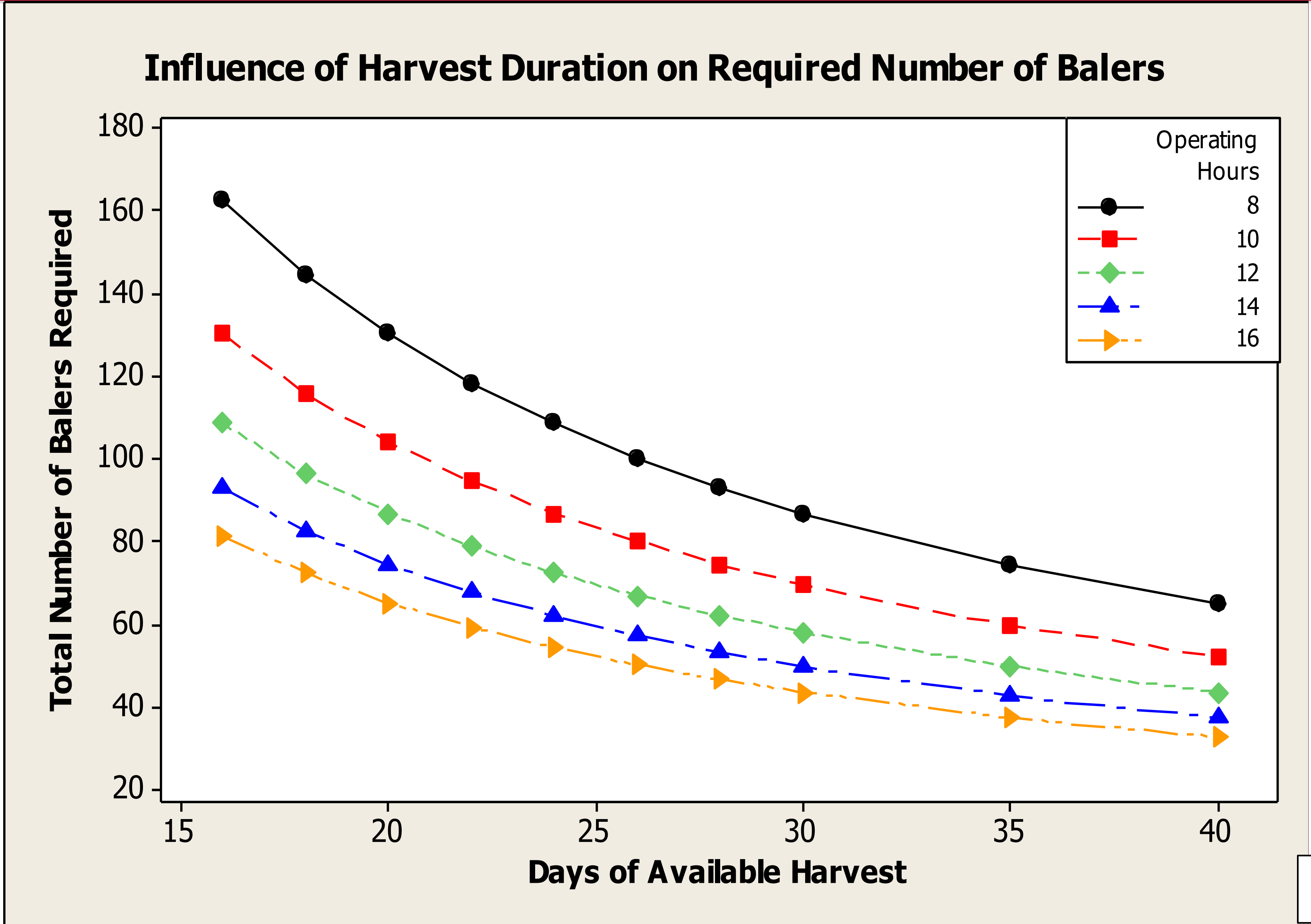
- Available harvesting window for corn stover.
- Impact of bale format on supply chain capacity.
- Long term solutions for feedstock storage.
- Understanding quality metrics and setting reasonable targets.

# Biorefinery Requirements

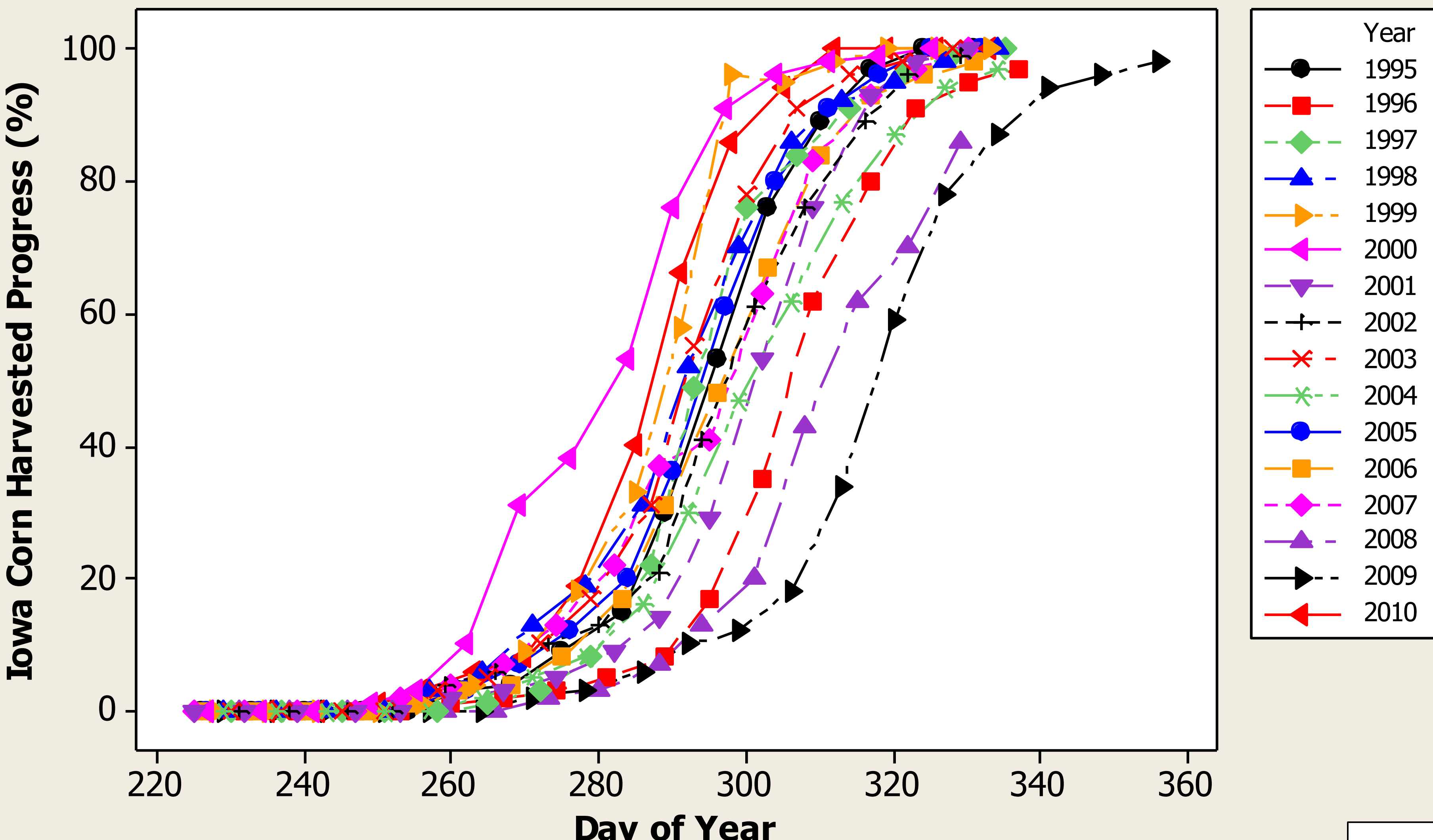
- 25 MMGY cellulosic ethanol plant will require 335,000 tons of biomass per year.
  - Approximately 670,000 large bales of corn stover per year.
- Biorefineries desire uniform feedstock with "low" ash content and "low" moisture content.

# Impact of Harvest Window

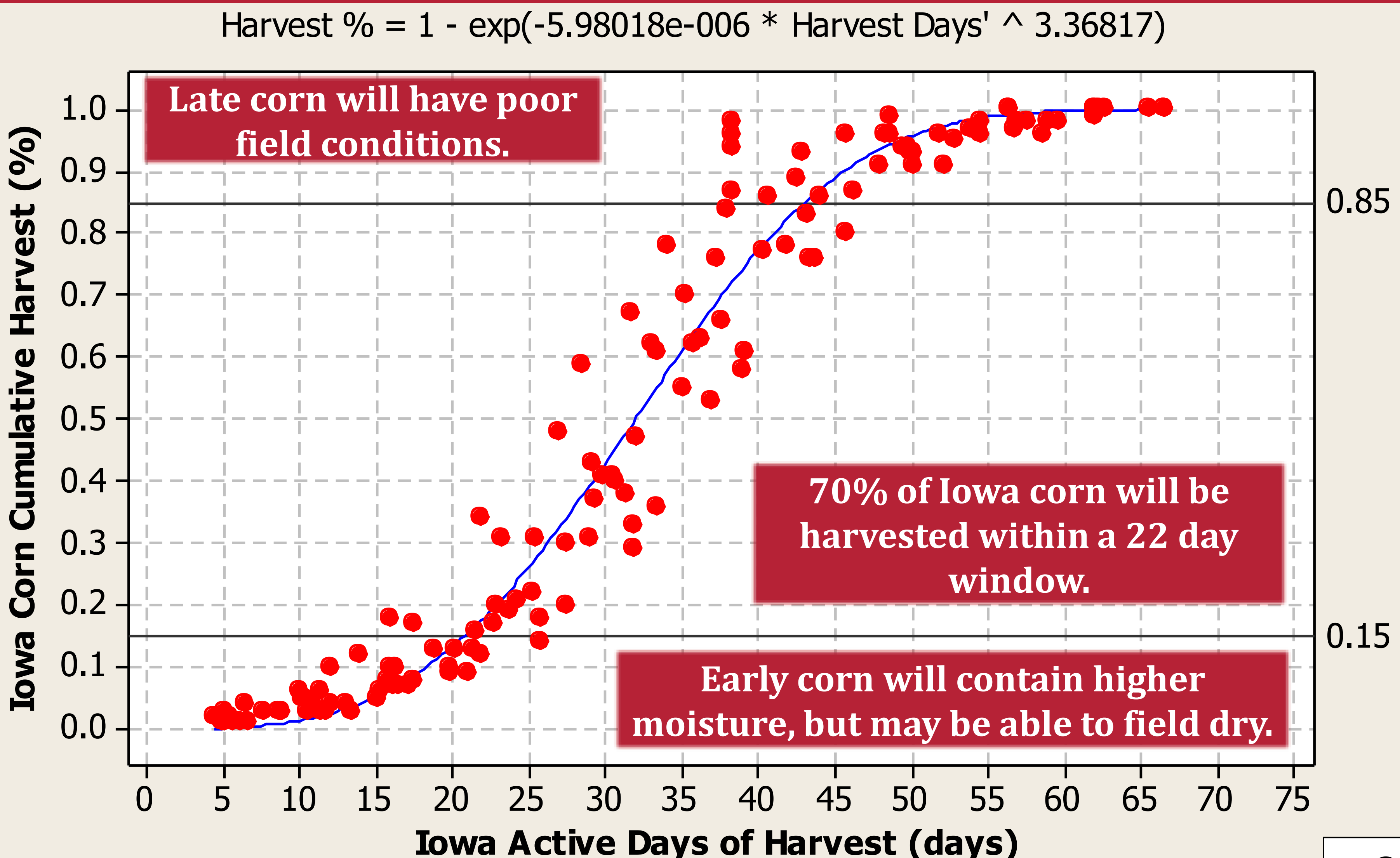
## Typical large square baler can produce 16 ton/hr of biomass.



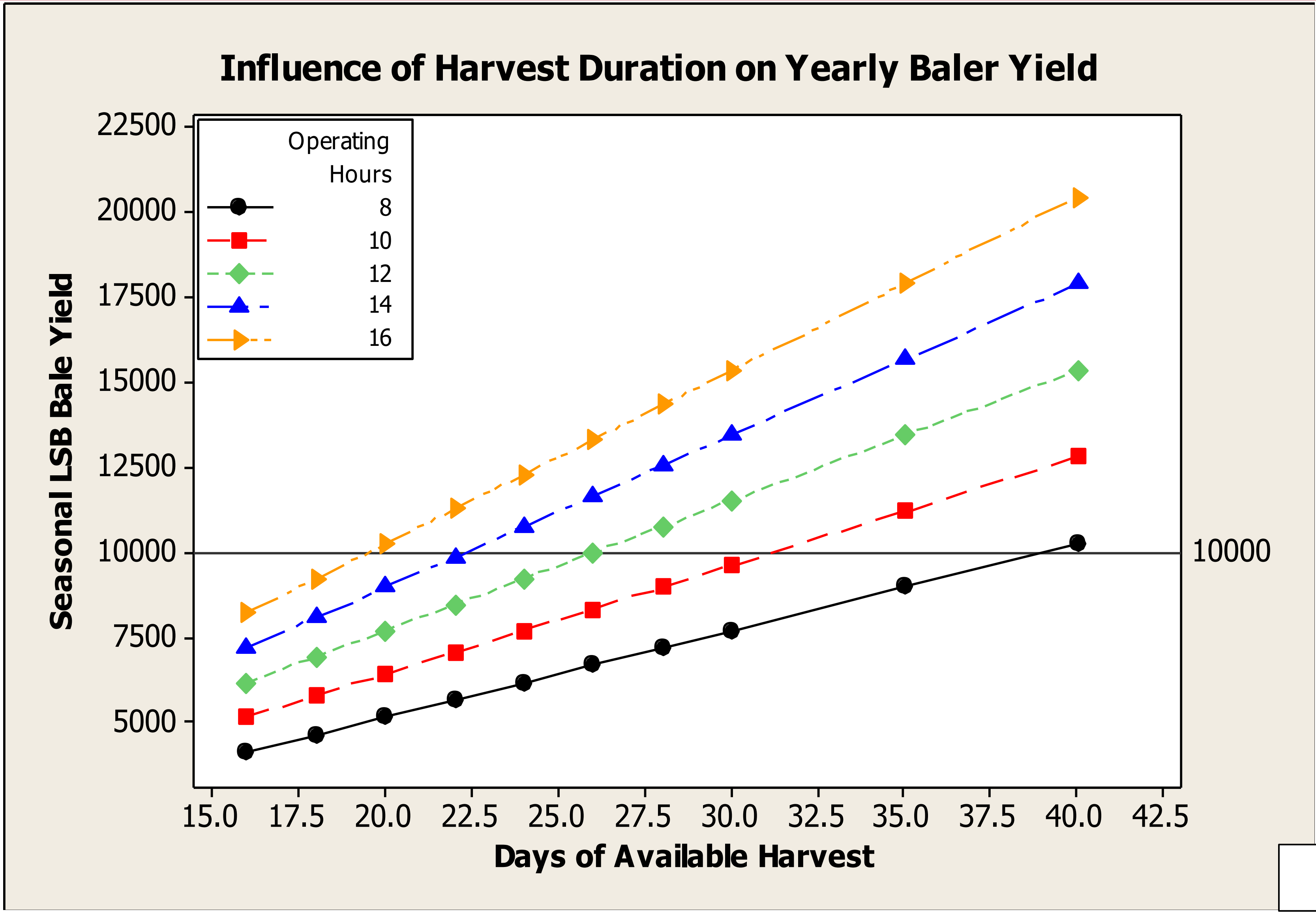
# Iowa Corn Harvest Timeline



# Iowa Harvest Rate from 1999 - 2010



# Baler Productivity



# 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: Verm

# 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.

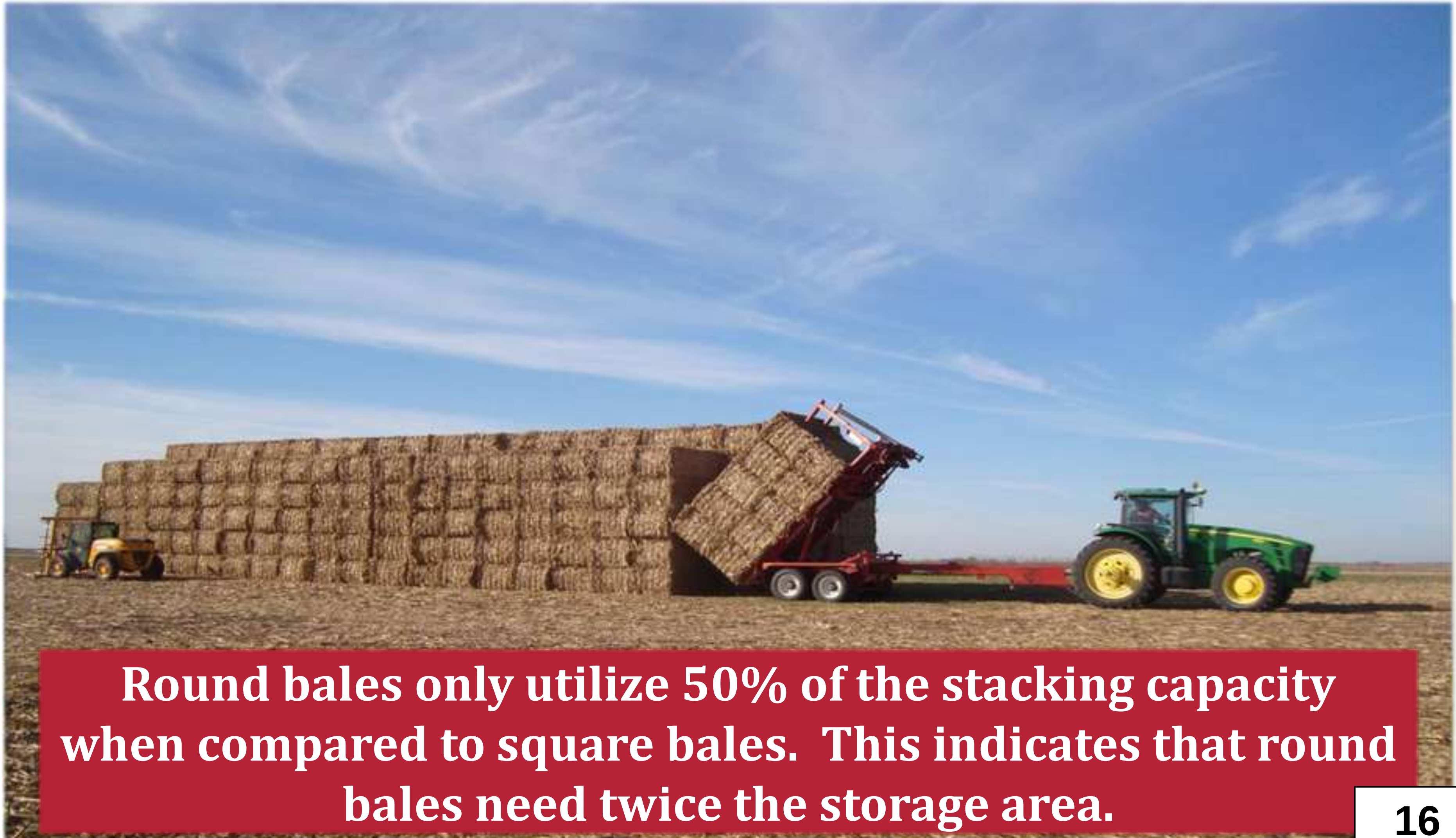
# Round Bale Handling

# 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

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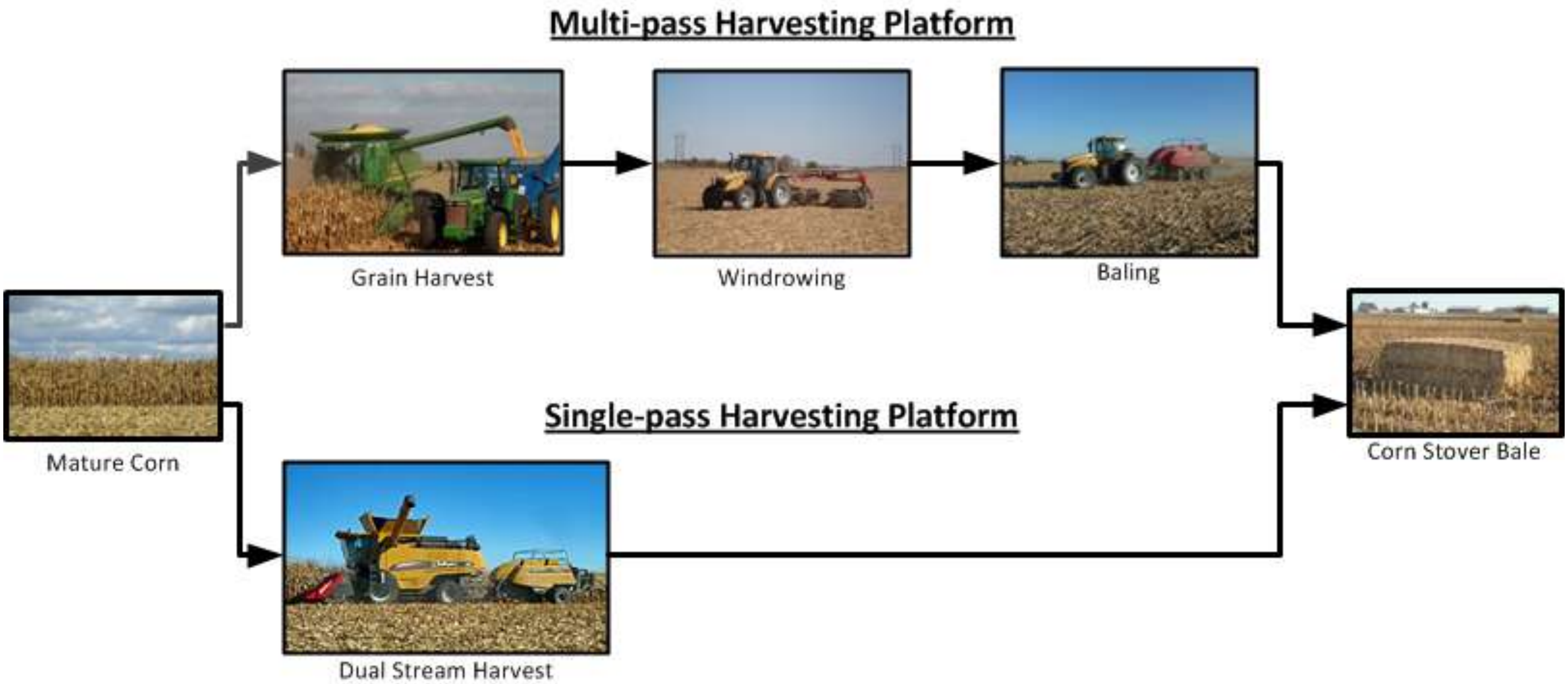
# Bale Uniformity and Durability

# Bale Format Comparisons

| | Baling Cost | Bale Collection | Bale Handling | Bale Stacking | Bale Transport | Bale Uniformity |
|---|---|---|---|---|---|---|
| Square | - | + | + | + | + | + |
| Round | + | + | - | - | - | - |

# Single Pass Baling Systems

# Advantages of Single Pass Baling



# 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

| | Stability | Cost | Access | Integration |
|---|---|---|---|---|
| Wrapped | + | O | - | - |
| Field Edge | O | + | - | O |
| Satellite | O | O | + | + |
| Hoop Barn | + | - | + | + |

# 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 that 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.

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# Configuring the Corn Stover Supply Chain

# 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


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# Questions