Improving Life through Science and Technology.

Harvesting, Handling, Transportation and Storage

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Background & Biases

• Expertise in machine system development with emphasis on cotton and biomass logistics

• Research is focused on energy sorghum, with some switchgrass and crop residue

• Collaboration with ag machinery companies
Biomass Supply Chain

• Expected to provide feedstock of
  – Required quantity
  – Required quality
  – Timely delivery
  – Sustainable cost
Logistics Myths/Assumptions

We have been mechanically harvesting biomass for decades. There are no significant technical barriers.

True – if you don’t care about cost
False – if we want biomass to replace fossil fuels
Logistics Myths/Assumptions

Cellulosic biomass is all pretty much the same, so the conversion plant will take most anything.

False – Collection, storage and processing operations all impact the biomass quality and energy recovery.
Logistics Myths/Assumptions

Moisture content doesn’t matter much if the haul distances are short.

False – Biomass harvested at 75% MC requires three times as many trips (trucks and drivers) as 25% MC material.
Supply Chain Principles

• Improve energy density at every operation
  – Field – maximize bulk density
    • Field dry to increase DM concentration
  – Regional – maximize energy density
    • Compress to higher density in package
    • Convert to energy form as close to field as possible
    • Leave conversion residues distributed
Supply Chain Principles

• Maintain biomass quality under varying moisture content at harvest
  – Carbohydrates consumed during storage result in lower energy content and higher ash
  – Mold may inhibit biochemical conversion efficiency
Supply Chain Principles

• Minimize machine system cost
  – Extend machine capacity with longer harvest season, higher efficiencies and low labor cost (custom operation model)
  – Take advantage of underutilized resources (individual farm model)
Supply Chain Principles

• Packaging method must provide
  – Enhanced handling
  – Extended storage period
  – Provide maximum legal truck loads
  – Minimum labor and load/unload times
Biomass Logistics Selection

The optimum feedstock supply chain is influenced by:

- Feedstock properties
- Local conditions (weather, labor market, etc.)
- Conversion process used
- Business model
Feedstock Influences

• Crop residues
  – Limited harvest window
  – Uncertain moisture content
  – Constraints of and on primary harvest objective
  – Net yield after conservation requirements uncertain
Feedstock Influences

• Perennial feedstock crops (switchgrass, miscanthus, arundo, etc.)
  – Potentially longer harvest window
  – Dry matter loss more critical since biomass is only source of value
  – High yields and crop physical characteristics influence drying rate
Feedstock Influences

• Annual feedstock crops (energy sorghum)
  – Variety selection allows long harvest season
  – Dry matter loss more critical since biomass is only source of value
  – High yields and crop physical characteristics influence drying rate
Conversion Influences

• Thermochemical
  – Smaller particle size required
  – Moisture content more critical

• Biochemical
  – More forgiving of particle size and moisture content
  – pH can affect enzymatic processes
Business Model Influences

• Custom Harvest Model
  – Farmer grows biomass, contractor schedules and performs all harvest operations
  – Based on high capacity machines, minimal labor

• Farmer Harvest Model
  – Farmer performs all operations
  – Utilizes available resources for low cost
1st Generation Logistics

Field

Conditioning

Bale

Load onto semi-trailer

Biomass Drier

Grinding

Transport bales from field

Plastic wrapped bales for storage

Refinery
Mower/Conditioners

Photo courtesy of Carol Jones, Oklahoma State University
Commercial Units in Biomass

• High yield may require slower speeds
• High yield can result in poor conditioning
• Harvest efficiency can be reduced
• Difficulty with lodged crops, a frequent occurrence with dedicated energy crops
MoCo Experiences

• Texas – energy sorghum
  – Compared four commercial designs
  – All experienced generally similar results
Harvesting Equipment

• Four Windrower/Conditioners
  – MacDon M200 with Auger Header
  – MacDon M200 with Disc Header
  – John Deere 4995 with Flail Conditioner
  – John Deere 4995 with Tri-Lobe Conditioner

*Both MacDon machines had “N bar” conditioner rolls
*Both John Deere machines had rotary disc headers
### Results

#### Avg. Windrow Efficiency

<table>
<thead>
<tr>
<th></th>
<th>D3</th>
<th>DF</th>
<th>MA</th>
<th>MD</th>
<th>Cutting Avg.</th>
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<tbody>
<tr>
<td>Aug 1st Cutting</td>
<td>92.8%</td>
<td>93.3%</td>
<td>95.9%</td>
<td>95.7%</td>
<td>94.4%</td>
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<tr>
<td>Aug 2nd Cutting</td>
<td>93.6%</td>
<td>91.9%</td>
<td>96.9%</td>
<td>93.4%</td>
<td>93.9%</td>
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<td>Oct Cutting</td>
<td>82.3%</td>
<td>72.2%</td>
<td>86.5%</td>
<td>88.6%</td>
<td>82.3%</td>
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<tr>
<td>Nov Cutting</td>
<td>*</td>
<td>*</td>
<td>82.4%</td>
<td>83.5%</td>
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<td>Jan Cutting</td>
<td>88.3%</td>
<td>#</td>
<td>82.6%</td>
<td>91.8%</td>
<td>87.9%</td>
</tr>
</tbody>
</table>

Machine Avg. 90.8% 88.4% 92.5% 92.1%

Row means with same letter are not significantly different.

* John Deere machines were not available for November cutting.

# The Jan Cutting DF area was not sampled from because of lack of machine performance.
MoCo Experiences

• Oklahoma – energy sorghum
  – Performed well in standing crop
  – Higher losses when lodging
  – Required two weeks to dry to safe moisture

• Oklahoma – switchgrass
  – Performed well in yields of 8+ DMT/ac
  – Achieved 12% MC after only one day
Rakes
Raking Experiences

• Texas – energy sorghum
  – Used to enhance drying for yield of 10-12 DMT/ac
  – Performance degraded by uncut stalks and random oriented long stalks
  – First windrow turning – 0.25-0.5 mph
  – Subsequent turning – 8-10 mph
Balers
Baling Experiences

• Texas – large square sorghum bales
  – Generally good performance
  – Difficulty with pickup teeth, attributed mainly to problems with uncut stalks
  – Problems with plugging when windrows are wider than pickup
Baling Experiences

• Oklahoma – large square bales
  – Generally good performance with both sorghum and switchgrass

• Oklahoma – large round bales
  – Typically poor bales in switchgrass due to low densities
Baling Power Requirements

Source: Krone Big Pack-Equipment.pdf
Department of Agricultural and Biosystems Engineering

Bale Handling

Photo courtesy of Matt Darr, Iowa State University
Bale Handling

• Equipment developed for hay handling functions equally well with biomass bales

• Capacities may be limited due to bale weights, particularly with high MC

• Time to load a semi-trailer is 20-30 minutes
Telehandlers for Energy Crops?

Source: Krone Big Pack-Handling.pdf
Storage

• Excellent work done by Oak Ridge National Lab

• Choice is cost trade off: $ invested vs. $ lost in DM

• Options range from uncovered storage of round bales to storage buildings

• No significant difference from hay

• Major issue is wet bale storage
Forage Harvesters

• Adequate capacity in current models
• Standing crop – row-independent headers
• Field dried crop – windrow pickups
• Combines harvest and particle size reduction operations
Theoretical chop length is only an indicator of the distribution of particle sizes
Storage

Storage of Chopped Biomass

- Alternatives similar to silage systems with same advantages and disadvantages
- Major additional disadvantage is need to remove from storage and haul to conversion site
- Less than maximum DM loads due to low DM density in trailer
2\textsuperscript{nd} Generation Logistics

Photo courtesy of Matt Darr, Iowa State University
Single Pass Harvesting Technologies

- **Positives**
  - Allows flexible and selective collection
  - Provides greatest percentage of harvestable material
  - Can collect stover or cobs only

- **Negatives**
  - Reduces harvest capacity of combine
  - High in-field logistics needs
Current Production Costs

Production Costs of Viable Systems

- **Single Pass Bag Silo**
- **Single Pass Bunker Silo**
- **Baled Stored Outside**
- **Baled Stored Inside**

- Orange: Transport to Biorefinery
- Blue: Storage
- Green: Upgrade
- Yellow: Transport to Storage
- Red: Harvest
- Light Blue: Nutrients
2nd Generation – Texas Activities

- Field
- Residues
- Biomass Drier
- Mobile Pyrolysis
- Transport oil
- Form pile
- Refinery
- Form module
- Storage
- Transport modules

Activities:
- Chop Form
- Module
- Transport
- Refinery
- Mobile Pyrolysis
- Biomass Drier
- Condition
- Form pile
- Residues
Moisture Insensitive System of Large Anaerobic Packages Based on Silage/Cotton Operations
Loading and Unloading Energy Sorghum Package
Results to Date

- Proof of concept with cotton equipment – labor intensive
- Proof of concept packages – 4-5 DMT
- Load/unload package in 90 seconds
- Package maintained form after 60 miles of transport
- 85% of material same quality as harvested after 9 month storage
IBSAL Cost Comparison

IBSAL Simulation Conditions
Switchgrass @ 10 DM ton/ac, 50 mile haul

<table>
<thead>
<tr>
<th>Process</th>
<th>Other Operations</th>
<th>Transportation</th>
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<td>Silage</td>
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Summary

Photo courtesy of Matt Darr, Iowa State University
Summary

• Existing forage and silage systems not likely to meet cost limits

• Optimum systems will be crop, location and conversion process specific

• Second generation logistics systems under development and show promise
Acknowledgements

• US Department of Energy
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