BALES Biomass Alliance for Logistics Efficiency and Specifications

DOE Bioenergy Technologies Office (BETO) 2019 Project Peer Review

Demonstration of an Advanced Supply Chain for Lower Cost, Higher Quality Biomass Feedstock Delivery

March 6, 2019

Feedstock Supply & Logistics Session

Kevin Comer, Sr. Project Manager
Antares Group, Inc.

This presentation does not contain any proprietary, confidential, or otherwise restricted information

Goal Statement

- To develop and demonstrate new and improved harvest and processing technologies that will **lower biomass supply chain costs** to $53/DT (harvest and transport to "throat of conversion reactor") while **improving feedstock quality**, **validating improvements and remaining gaps**, and **addressing key sustainability issues** in order to promote a sustainable and scalable advanced biofuels industry.

Targeted Project Outcomes

- Cost reductions for advanced large scale feedstock delivery and processing estimated to be ~$18 per ton (conservative)
  - Worth $5.4 million/yr at 300,000 ton/yr scale
- Identify and measure all supply chain costs
- Improve feedstock quality measurement through rapid NIR spectroscopy
- Improve automated multi-bale receiving, handling, processing systems

Successful demonstration of these technologies in a commercial environment will support the increased production of cellulosic biofuels/bioproducts in the United States.

BALES Biomass Alliance for Logistics Efficiency and Specifications

Quad Chart Overview

Timeline

- Project start date: 9/30/2013
- Project end date: 3/31/2019
- Percent complete: 99+%

Barriers

- Ft-H. Biomass Material Handling and Transportation
- Ft-E. Feedstock Quality: Monitoring and Impact on Preprocessing and Conversion Performance
- Ft-D. Sustainable Harvesting

Budget

Source of Funds	Total Costs Pre-FY17	FY 17 & FY18 Costs	Total Planned Funding (FY 19-End)
DOE Funded	$5,188,822	$766,668	$326,792
Project Cost Share by Contributing Partner			
Vermeer	$5,266,852	$1,229,808	$1,286,836
Kelderman Mfg.	$582,028	$244,009	$42,808
Feedstox	$153,197	$0	$0
Poet Biomass	$337,862	$0	$0
John Cundiff	$27,861	$0	$0
ASDI	$1,276	$0	$0
Virginia Tech	$39,703	$0	$0
Collaborators	$1,392,022	$619,291	$0
Monsanto	$881,752	$0	$0

Partners

- Vermeer (42.9%)
- FDC Enterprises (13.4%)
- Collaborators (12.4%)
- Kelderman Manufacturing (8.6%)
- Monsanto (7.8%)
- Antares Group Inc. (4.8%)
- Poet Biomass (2.5%)
- Idaho National Laboratory (2.0%)
- John Cundiff (1.8%)
- Virginia Tech (1.8%)
- B Hames Consulting (1.6%)
- AgSolver (0.2%)
- ASDI (0.02%)

1 - Project Overview

- Leveraging team member's operational experience, knowledge, and capabilities to identify and resolve existing supply chain challenges.
- Building on team's prior square bale system development work
- Address opportunities in round bale systems
  - Over 90% of existing baling stock are round balers. (big factor for scale-up)
- High-volume, multi-bale handling systems are needed to reduce trucking costs and wait times.
- Dirt reduction early in supply chain is critical
  - Harvest improvements and advanced instrumentation targeted
- Automated bale handling systems need to be capable of handling extremes, not average delivered biomass
- Particle size control and uniformity improvements targeted
  - Continued improvements will be needed

2 – Approach (Management)

- ***Team members planned development and testing schedule for 4 yr period.***
- ***Used DOE budget and progress reporting system to track and report progress.***

PROJECT ROLES:

FDC Enterprises: Prime contractor, lead harvest & logistics operations

POET, Clariant, ADM: Biorefiner team members, provide process material spec's

POET: Biomass harvest end-user

Vermeer: Equipment development for round bale harvest, logistics, processing

Kelderman Manufacturing: Equipment development for square bale harvest, logistics, at-plant bale handling

MacDon: Collaboration with Kelderman on windrow merger

Bonnie Hames: Lead NIR expert for calibration model for bale probe development

ASDI: Spectroscopy equipment vendor, bale probe development

Monsanto: Facilitated access to multi-year bale storage study; Lab analysis for NIR

INL: Bale probe sampling, lab analysis, pilot-scale process demonstration testing

John Cundiff, SeaBox, Virginia Tech: Round bale hauling and rapid-unloading system

Antares Group: Project management and coordination, data collection & analysis

2 – Approach (Technical)

- Develop and Demonstrate New or Improved Biomass Harvesting, Logistics, Processing, and Analysis Equipment
  - Designed equipment to fill gaps in the biomass supply chain (harvest and processing), for square and round bale systems
  - Continuous development cycle (Design → Build → Test → Learn → Improve)
  - Improved in-field harvest data collection systems to build a more robust set of cost and performance data (share data with National Labs)

- Critical Success Factors and Key Challenges
  - Prototype equipment and innovations fabricated and tested.
  - Proving equipment reliability to meet commercial product requirements.
  - Need continued demonstration and development platforms/opportunities, supplemental funding.
  - For process technologies: Need regularly operating demonstration facilities with local biomass supplies and nearby offtake opportunities, supplemental funding. (Demonstration test-beds needed.)

Advanced Feedstock Supply Chain - Large Square Bale Format

Standard Process
Optional Process
MC Moisture Quality Assessment
NIR Near Infrared Quality Assessment

1 Advanced Baling

2 Advanced Roadsiding

3 Direct Transfer to Self Loading Trailer

4 Advanced Transport

5 Optional Field- side Storage

6 Bale Pre-loader

7 Optional Plant-site/depot Storage

8 Bale Pre-loader

9 In-feed Conveyor

10 Automatic Destacking

11 Bale Singulation Conveyor

12 Bale Q/A & Analysis (Bale Weight & NIR)

13 Bale Rejection Conveyor

14 Automatic De-stringing

15 De-baling (Stage 1 Grinding)

16 Transfer Conveyor & Foreign Material/Metals Removal

17 Stage 2 Milling (Fine Grind)

18 Primary Cyclone

Fines/Dirt

19 Cyclone Baghouse

20 Dirt/Organic Fines Separation

Organic Fines

21 Dirt

Larger Particles

22 Surge Bin

23 Conversion or Densification Process In-feed

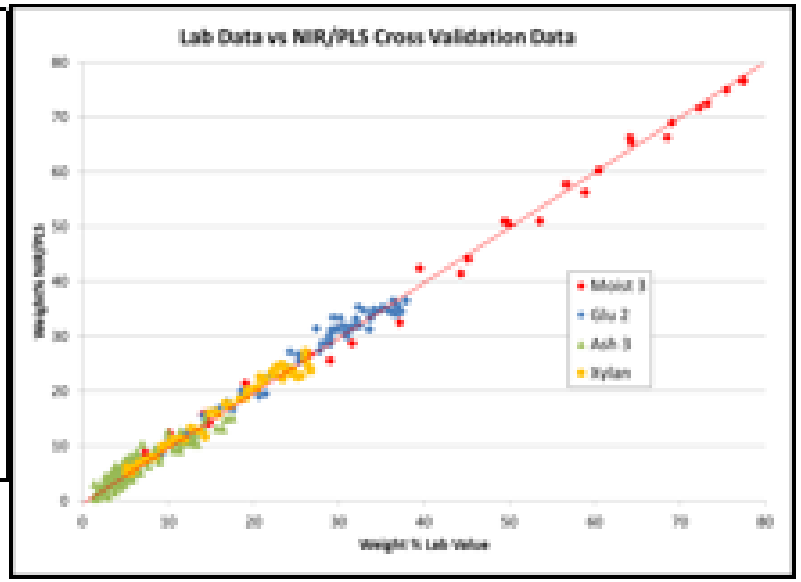
Similar Work for Large Round Bales

NIR Bale Probe Development and Demonstration

NIR/PLS Model	Moist 4	Glu 2	Xyl 2	Ash 3
Cal. Range (%)	4 - 80	5 - 40	5-27	0.5 - 19
RMSECV (%)	2.4	1.5	1.1	1.3
Factors	1	3	3	1
R^2	0.985	0.969	0.977	0.787
N	33	68	54	162
Moist. Range (%)		4-60	4-60	4-70

Calibration Stats.

Successful development of mechanical deployment systems for field and process.



Comparison of Lab and NIR analysis

- ASDI, INL and BHC have designed and calibrated a NIR Bale Probe accessory for the ASDI Field Spec.
- Updated PLS methods measure moisture, ash, glucan and xylan in corn stover.
- Proprietary techniques allow for constituent analysis at moisture levels up to 60%
- Probe design updated to make it more rugged for in-field use and transport

Harvest, Handling, & Pre-processing Results

- Began testing of variable rate Cornrower™ header
  - Improved stover yields from first harvest pass (grain harvest), low dirt/ash, control of sustainable removal rates
- Demonstrated reliable operations at 10% higher density bales
  - Round and square
- Demonstrated reliable lower ash harvest ops., ~3% to 6%
- Demonstrated 6-bale accumulator (vs. 1), square bales
- Demonstrated windrow merger → ½ baler travel
- Demonstrated new square bale gathering vehicle
  - 6 bales per pick (vs. 1), 36 bales per trip (vs. 8-12)
- Demonstrated self-unloading trailers, 5-10 min. load/unload times
- Demonstrated new round bale infeed system, 80,000 bales
- Demonstrated multi-bale round bale handling & unloading system
- Demonstration & parametric testing of new grinding machine

Initial Prototype Testing

Rapid multi-bale infeed system under development by other team members

Final Prototype Testing at Biorefinery (80,000+ bales processed, now a commercial product)

Bale Handling System

Vermeer

EQUIPPED TO DO MORE.

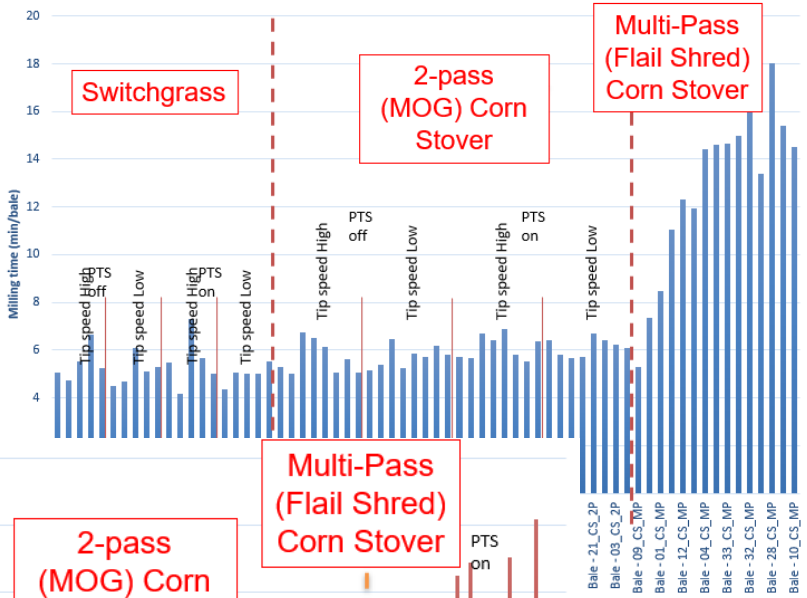
Square Bale Infeed, De-stacking, Conveyance System

Kelderman

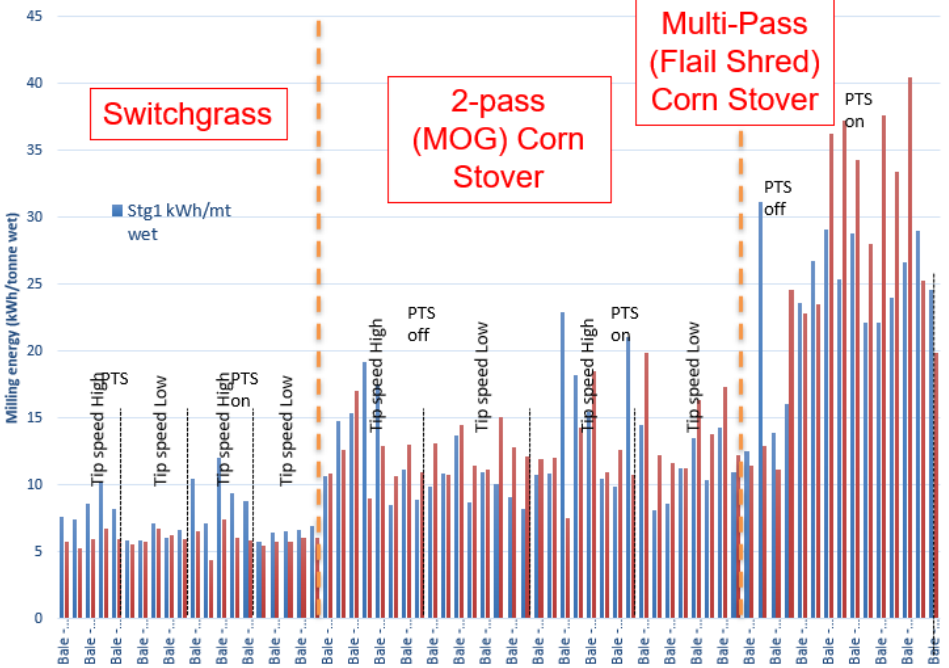
Pre-process Testing at INL PDU

- 3 bale types
- Same equipment & settings
- ~2x to 4x more time for Flail-shredded bales
- ~2x to mill MOG stover vs. SWG
- ~2x-4x to mill Flail Shredded Stover vs. MOG
- Hit process specs. via multiple operations
- Demonstrated NIR probe in process

Processing Time



Milling Power



4 – Relevance

- The project's objectives align with the BETO's goals to provide biomass feedstocks at or below $84/DT.
  - The biomass harvesting and processing equipment being developed and demonstrated under this project has demonstrated potential to help reach this goal.

- Developing rapid analysis tools and methods to enable more-efficient and lower-cost feedstock quality assessment throughout the supply chain.
  - This aligns with BETO's goals for "Terrestrial Feedstocks" (found in Biomass Program Multi-Year Program Plan)

Summary

1. **Approach**:
   - Aggressive set of equipment development goals and objectives, round and square bales.
2. **Accomplishments**:
   - All scheduled equipment developed and demonstrated, improvements are in-progress
   - Demonstrated results in NIR spectroscopy for rapid biomass quality analysis, improvements ongoing
   - Significant equipment performance and biomass quality data collection
   - New/unique results from square bale batch testing at INL PDU, Vermeer prototype grinder
3. **Relevance**:
   - Significant cost reductions and reliability improvements are needed in feedstock delivery and processing systems—primary focus of this project.
4. **Success Factors and Challenges:**
   - Success Factors: Collaboration, Team capabilities and breadth
   - Challenges: More heavy crop acres desired, more demonstration activities needed, continued refinement of equipment
5. **Future Work:**
   - Complete and document testing and results for:
     - Bale pre-loader
     - Square bale infeed, de-stacking, & conveyance system
   - Final project report
   - Contract close-out

BACK-UP SLIDES

Examples High-volume Unloading Systems

Cotton Gin

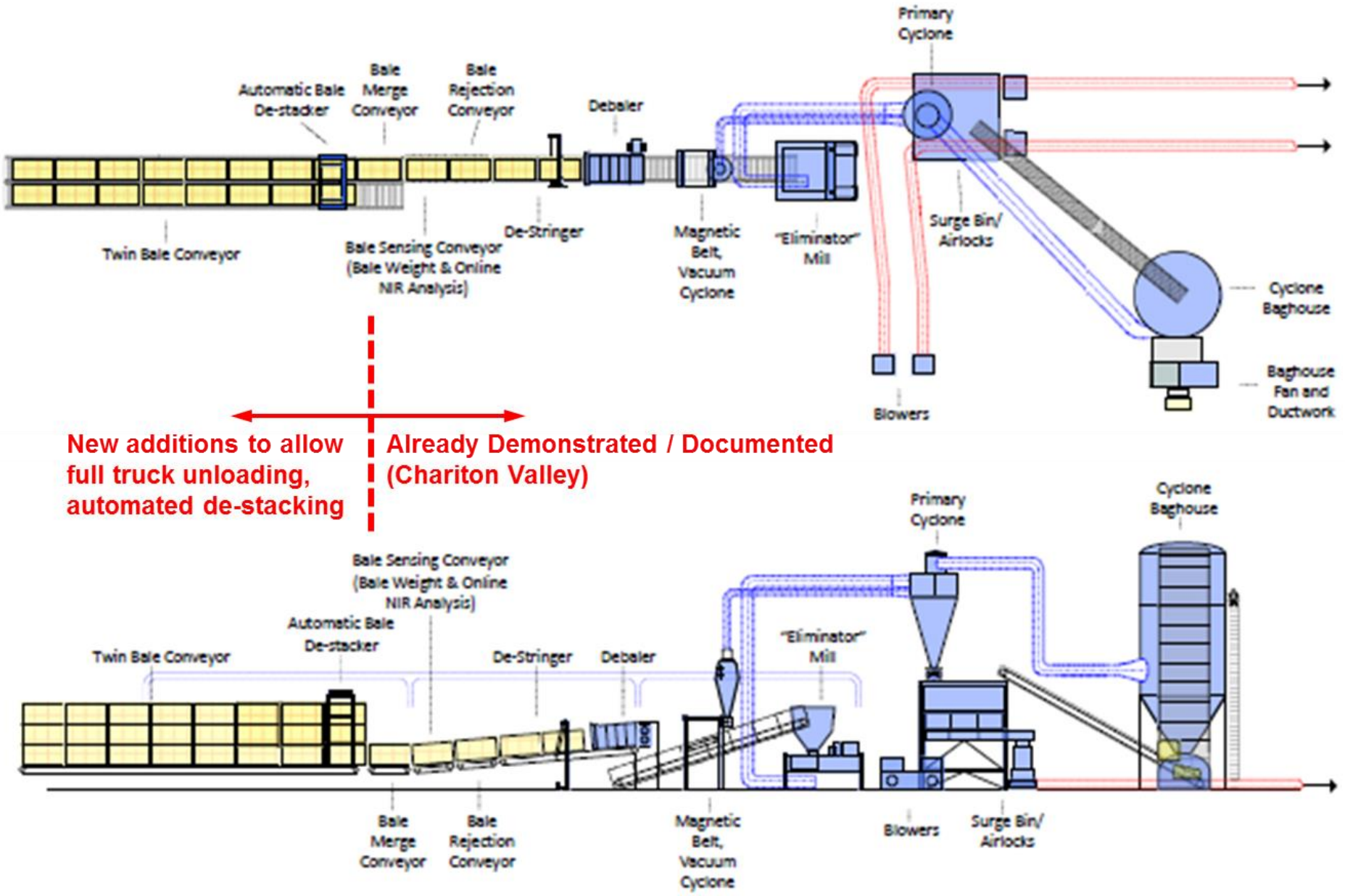
Log Trailers

Sugar Mill

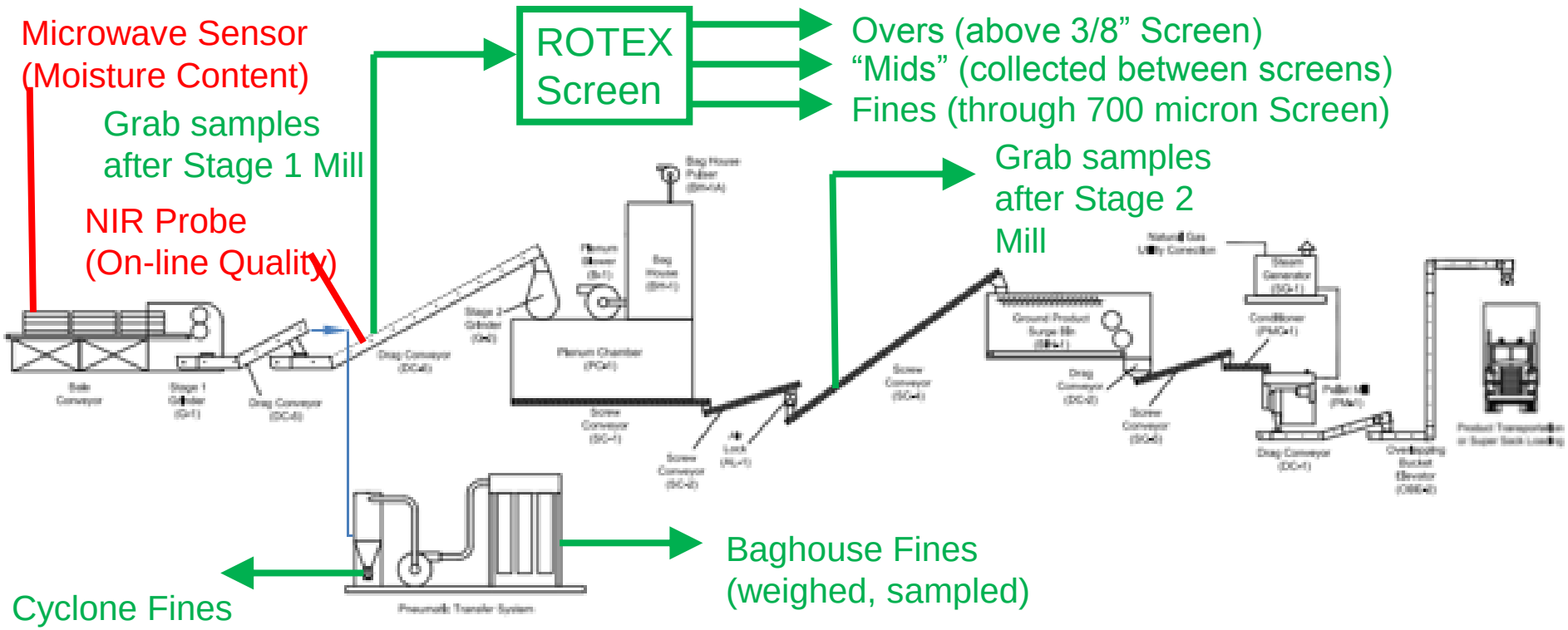
Example High-volume Infeed Systems

BALES Biomass Alliance for Logistics Efficiency and Specifications

Process Line Concept Drawing



Process Test Set-up -- INL PDU (~5 ton/hr)



Other Measurements:

Power consumption, equipment level

Air flow rates

Biomass feed rates

VSD settings, Bale Moisture by Hay Probe

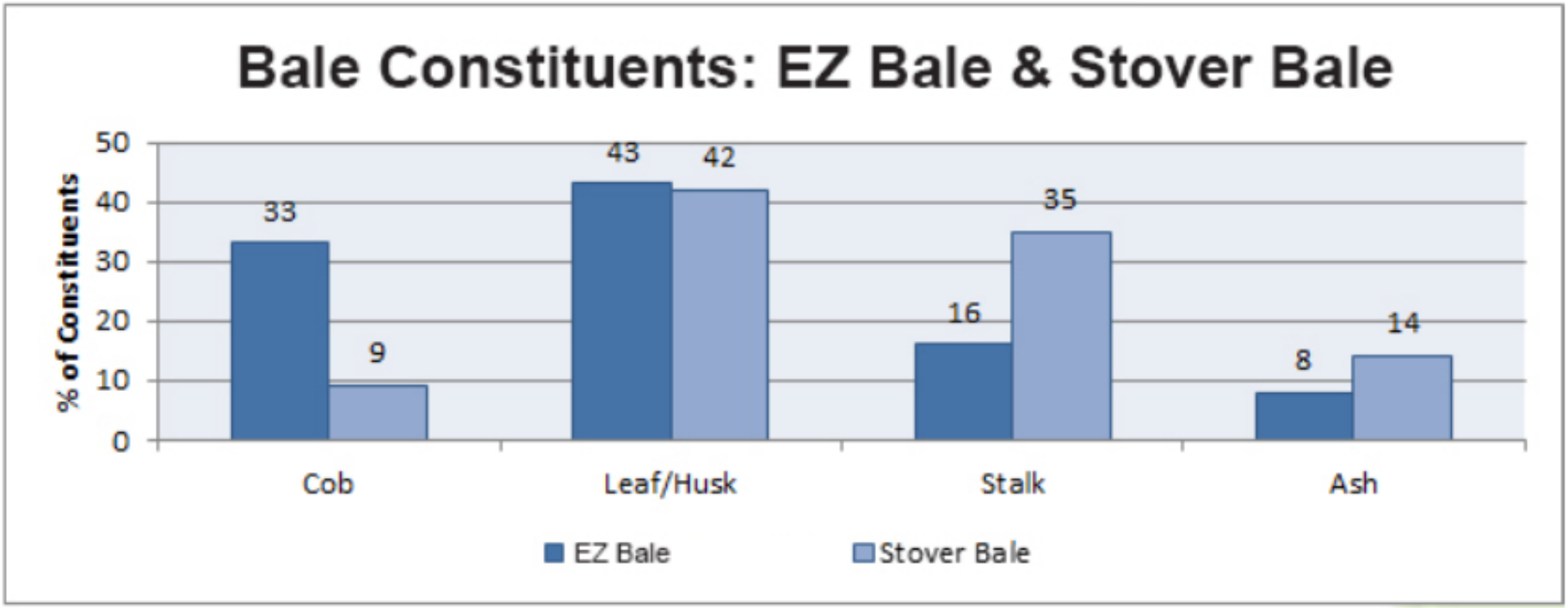
Test Objectives

- Can we hit biorefinery specs?
  - We targeted two distinctly different specs:
    - Course: >1”-minus, with minimal fines, minimal dirt
    - Fine: ~1/8”-minus, minimal dirt
- What impacts do biomass type, quality, and characteristics have on performance, production, yielded material on-spec.?
- Could a more sophisticated control system improve overall production & performance?
- Initial process line testing of new NIR biomass probe
- Identify challenges / opportunities for improvement

General Sampling Plan

- Bales
  - 33 switchgrass from U of Ill.
  - 36 stover from Pocahontas Co. (POET)
  - 35 stover from Boone Co. (DuPont)
- 3 batches, 4 process test conditions each (planned)
- Focus on material properties
  - Particle size
  - Size distribution
  - Aspect ratio
  - Ash & Moisture content (Sugars as possible via NIR)
  - Screening (orbital & air classification)
- NIR biomass probe process line proof-of-concept

Primary Differences in Corn Stover Tested



Post-processing (Rotex) "Gyratory Reciprocating Motion"

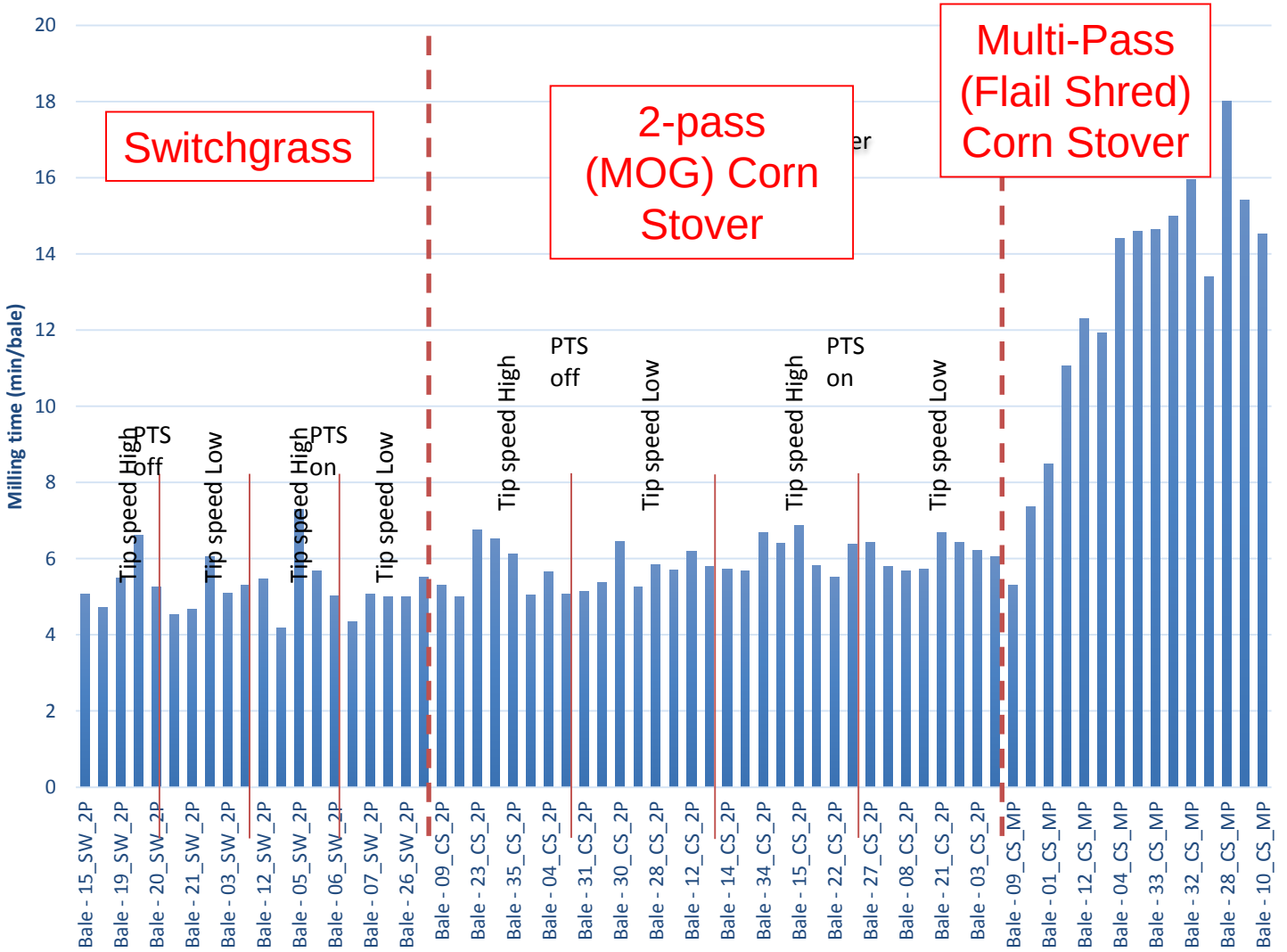
Test Run Settings (as Tested)

Batch No.	Biomass Type	No. of Bales	Bale Infeed Conveyor Set Rate	Stage 1 Mill Speed	Pneumatic System (On (Rate)/Off)	Mill Screen Sizes	
1	Switchgrass	5	6 Hz	51 Hz	Off	Stage 1: 3" Stage 2: 1"	Relatively Easy Processing
		5		41 Hz	Off		
		5		51 Hz	On (20 Hz)		
		5		41 Hz	On (20 Hz)		
2	Corn Stover (POET EZ-Bale)	8	6 Hz	51 Hz	Off	Stage 1: 3" Stage 2: 1"	Relatively Easy Processing (~2x Milling Power vs. SWG)
		8		41 Hz	Off		
		8		51 Hz	On (20 Hz)		
		8		41 Hz	On (20 Hz)		
3	Corn Stover (DuPont Flail Shredded)	6	6 Hz	51 Hz	Off	Stage 1: 3" Stage 2: 1"	High Degree of Difficulty (~7x Milling Power vs. SWG)
		Abandoned	N/A	41 Hz	Off		
		3	4 Hz	51 Hz	On (50 Hz)	Stage 1: 3" Stage 2: 1/2"	
		4		51 Hz	On (35 Hz)		
		2		51 Hz	On (50 Hz)	Stage 1: 3" Stage 2: 3/4"	

3 – Pre-processing Tests at INL PDU

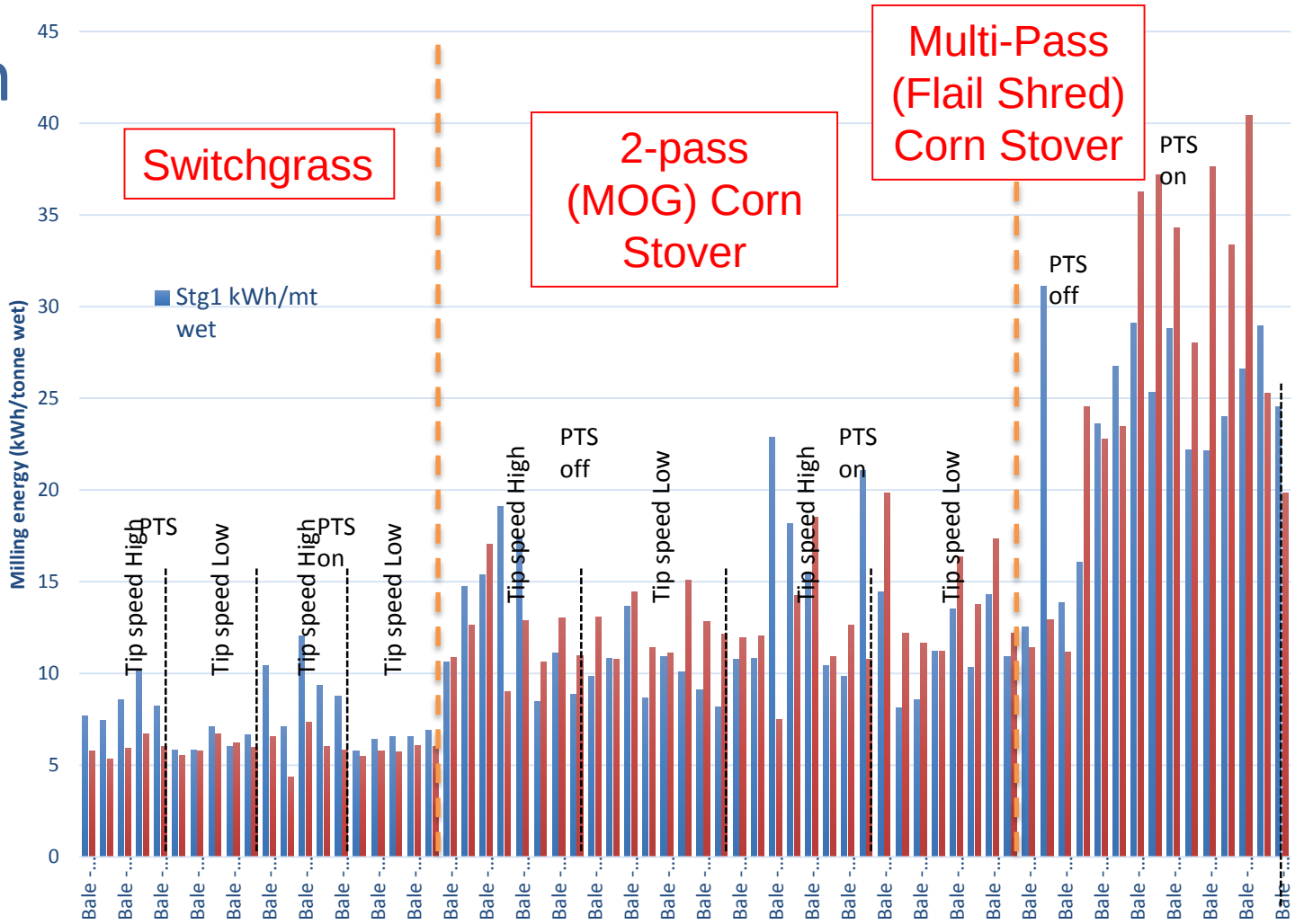
Milling Time (min/bale)

- Pre-process testing at INL PDU
- Same equipment & settings
- ~2x to 4x longer for Flail-shredded bales



Milling Power (kWh per tonne)

- ~2x to mill MOG stover vs. SWG
- ~2x-4x to mill Flail Shredded Stover vs. MOG



Air Separation Results

Batch No.	Biomass Type	Bale IDs	Pneumatic System (On (Rate) / Off)	Stage 1 Mill Speed (Hz)	Total Bale Weight (lbs.)	Cyclone Fines		Baghouse Fines		Total Removed by Air System (%)
						lbs.	% of Total Bale Weight	lbs.	% of Total Bale Weight	
1	Switchgrass	16 - 20	20 Hz	51	4,636	18.0	0.4%	13.5	0.3%	0.7%
		21 - 25	20 Hz	41	4,720	13.0	0.3%	9.0	0.2%	0.5%
2	Corn Stover (POET EZ-Bale)	42 - 49	20 Hz	51	7,619	39.5	0.5%	0.5	0.0%	0.5%
		50 - 57	20 Hz	41	7,994	36.5	0.5%	1.0	0.0%	0.5%
3	Corn Stover (DuPont Flail Shredded)	64 - 66	50 Hz	51	3,300	225.5	6.8%	16.5	0.5%	7.3%
		67 - 70	35 Hz	51	4,363	64.5	1.5%	4.5	0.1%	1.6%

Low

High

Low

- Relatively low amount of fines collected at 20 to 35 Hz on PTS VFD
- Relatively high amount of fines collected at 50 Hz on PTS VFD
- Fines appear to be mostly dirt, by weight (need to verify)
- NIR Biomass Probe accurately measured ash reduced by air system

Rotex Separation Results

Batch No.	Biomass Type	Bale IDs	Moisture Content (%)	Ash Content, Bale Cores (%)	Ash Content, After Stage 1 Grind (%)	Pneumatic System (On (Rate) / Off)	Stage 1 Mill Speed (Hz)	Separation Weights (lbs)			Separation Fractions (%)		
								Overs (Above 3/8" Screen)	Mids	Fines (Through 700 micron Screen)	Overs (Above 3/8" Screen)	Mids	Fines (Through 700 micron Screen)
2	Corn Stover (POET EZ-Bale)	26 - 31	16%	7%	7%	Off	51	39.5	26.5	4.0	56%	38%	6%
		42 - 49	22%	5%	5%	20 Hz	51	37.0	25.5	3.0	56%	39%	5%
		50 - 55	17%	6%	6%	20 Hz	41	44.0	20.5	2.5	66%	31%	4%
3	Corn Stover (DuPont Flail Shredded)	58 - 63	18%	8%	11%	Off	51	23.0	24.0	5.7	44%	46%	11%
		64 - 66	12%	7%	5%	50 Hz	51	18.0	11.5	9.0	47%	30%	23%

- High fractions of “Overs” (~34-66%) and “Mids” (~30-46%)
  - Two separate conversion trains? and/or Need uniformity improvements.
- Significantly more fines in flail shredded bales
  - More time in mill, higher dirt content

Can we do anything about dirt?

YES !

- Reductions in the field – deliver less.
- Air separation
- Screening
- Improved management systems
- Big $$ savings potential

BALES Biomass Alliance for Logistics Efficiency and Specifications

3 – Advanced Supply Management

Efficiently managing and optimizing all aspects of supply system—mature system from Finland to U.S.

NIR Probe Mechanical Deployment & Testing

"[Now that you've proven the probe and analysis works, come back to me when you can stick it into a bale without pre-drilling a hole and I'll be interested.]"

-- Adam Wirt, POET

Without mechanical deployment system:

TEST RESULTS:

- Developed & tested hydraulic deployment system
- 1,500 lbf. required for probe insertion, max 300 psi
  - 2 independent tests
- Protects probe & function

3 – Technical Accomplishments

"EZ-Bale"; ~ 1 ton/acre; No separate shredding

Separate shredding operation;
~ 2 ton/acre or more

Shredding in new header;
Optimized biomass removal rates;
Avoids separate shredding operation

Increased bale densities

Square Bales ⟷ Round Bales

10%+ more tons per truckload, 10%+ fewer trucks

3 – Technical Accomplishments

Reduced Dirt Content in Bales:

Previous norms: 8-10% (at best) ash

Current Potential: as low as 3% ash

AGCO Your Agriculture Company · John Deere · Hillco Technologies · New Holland Agriculture · Vermeer · Kelderman

Non-accumulated baling, 1 bale per drop

Baling one windrow at a time

Accumulated baling, 6 bales/drop

Kelderman MacDon

Windrow merger; combines 2 windrows into a single baling pass; ½ baler travel

3 – Technical Accomplishments

Current Bale Gathering; 1 bale at a time; ~8-12 bales per trip

Bale Picking Truck; picks up to 6 bales at a time; 36 bales per trip

Typical trailer loading / unloading; 1 to 6 bales at a time; 20-40 minutes

Self-Loading / Unloading trailers; 36 bales at a time; 5-10 minutes

BALES
BIOMASS ALLIANCE FOR LOGISTICS, EFFICIENCY, AND SPECIFICATIONS

Progress towards commercial supply chain

Feedstock quality

- Bale density testing
- Ash analysis – variables
  - Equipment settings
  - Field – soil type, conditions
  - Weather – before, during harvest
- Operator experience impact
  - Bales/hour
  - Maintenance & repair

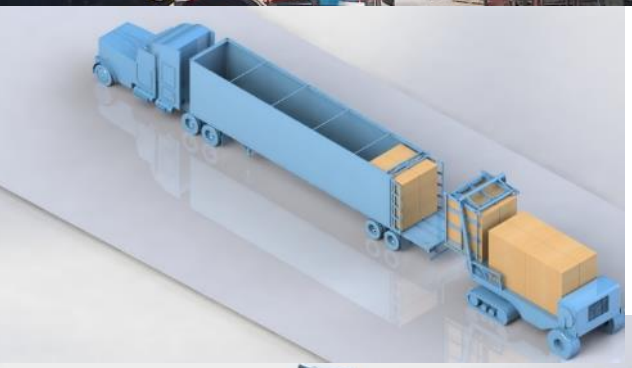
# of Bales	Average Density % increase
80	-11%
87	0%
82	11%
83	9%
72	12%
11	28%

Reducing cost of harvest

- Durability
  - Belt analysis
  - Pickup shut off during wrap
  - Drive system enhancements
- Analyze stop time causes
  - Replace netwrap roll was the top reason (16%)
  - Non-baler reasons (34%) operator, tractor
- Mapping harvest path
  - Custom harvesters travelled in excess of 1000 miles. Roughly 50% were road miles
- Continuous round baler prototype
  - Collected harvest data in 2016.

3 – Accomplishments
Bale Pre-loader

Loader arms and mast fabrication



3 – Full-scale Grinder Testing

- Extensive parametric performance testing to discover optimal process settings at full commercial scale
  - Electric-powered horizontal grinder model used (HG6000E)
  - 38 configurations with various screens and cutters
  - Collected moisture content, energy consumption, production rate, particle size
- Purpose-built biomass grinder, designed, built, tested

(Details masked for confidentiality reasons)