2013 DOE Bioenergy Technologies Office (BETO) Project Peer Review

Development of a Bulk-Format System to Harvest, Handle, Store, and Deliver High-Tonnage Low-Moisture Switchgrass Feedstock

May 19-23, 2013

Feedstock Supply & Logistics

Al Womac, University of Tennessee

Lead Organization: Genera Energy Inc.

Goal Statement

- *Develop and test bulk-format logistics for low-moisture switchgrass incorporating bulk-handled loose, bulk compacted with overburden, and bulk compacted with mechanical systems - comparing costs with round-bale logistics.*

- Supports "Advanced Uniform-Format Feedstock Supply System"
  - ✓ Distributed depots
  - ✓ Densification & Handling
  - ✓ Feedstock R&D harvesting, storage, handling & transportation for Ethanol Infrastructure
  - ✓ Perennial grass, dry herbaceous (<20% m.c. (w.b.))

- Results apply to bulk-format feedstock supply chain

- Important lessons learned that can be transferred to other feedstock supply systems include bulk handling after size reduction.

Quad Chart Overview

Timeline

- Project start date: July 30, 2010
- Project end date: June 30, 2013
- Percent complete: 95%

Barriers

- Barriers addressed
  - Sustainable Harvesting
  - Biomass Storage Systems
  - Biomass Material Handling & Transportation

Budget

- Funding for FY11(DOE $2.44M/ Cost share $2.79M)
- Funding for FY12(DOE $2.04M/ Cost share $1.94M)
- Funding for FY13 (DOE $316k/ Cost share $435k)
- Years the project has been funded (3)

Avg. annual funding (DOE $1.6M/ Cost share $1.72M)

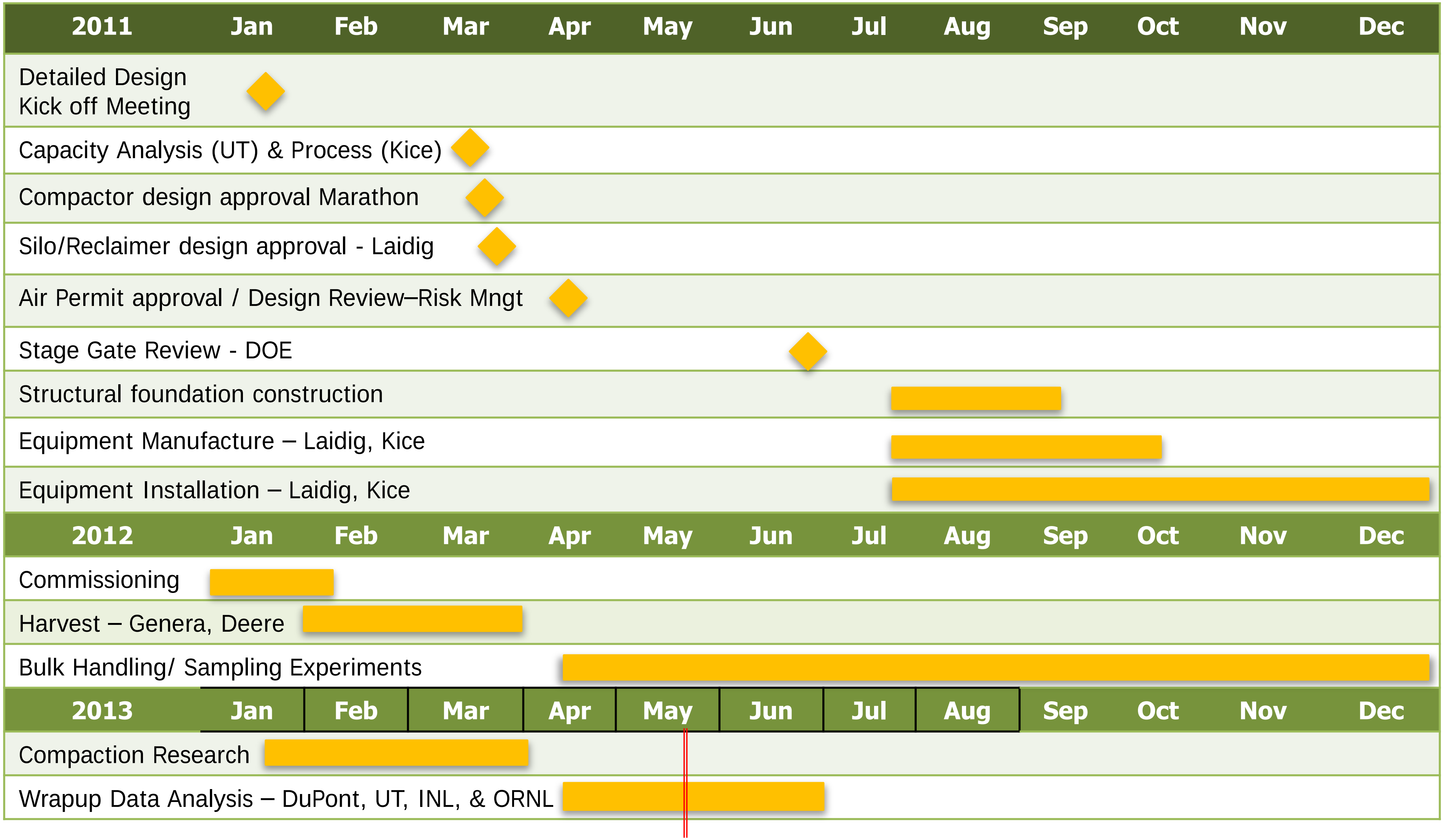
Partners (Next Slide)

Genera Energy, UT, Laidig, Marathon, Kice, John Deere, INL Idaho National Laboratory, Oak Ridge National Laboratory, DuPont

Collaborations /Project management

- Project Partners/Roles
  - **Genera Energy** – Switchgrass, farmers, storage and handling
  - **University of Tennessee** – Logistics analysis, reporting
  - **Laidig Systems** – Storage and reclaiming
  - **Marathon Equipment** – Bulk compaction
  - **Kice Industries** – Material conveyance and dust collection
  - **Deere & Co**. – Harvest equipment
  - **Idaho National Lab** –Material properties analysis
  - **Oak Ridge National Lab** – Independent cost analysis
  - **Dupont Cellulosic Ethanol** – Feedstock analysis
- Project Management
  - **Genera Energy** – Coordinates with partner input; permits, construction, and contracts

Project Overview - History



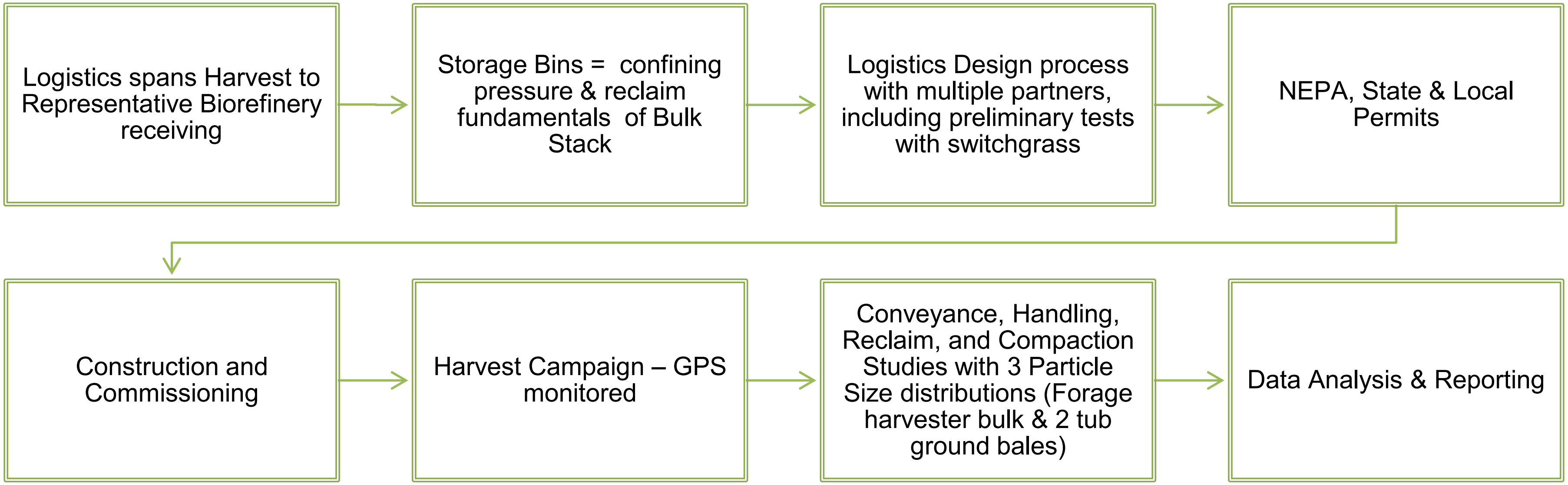
Project Overview - Objectives

Objectives

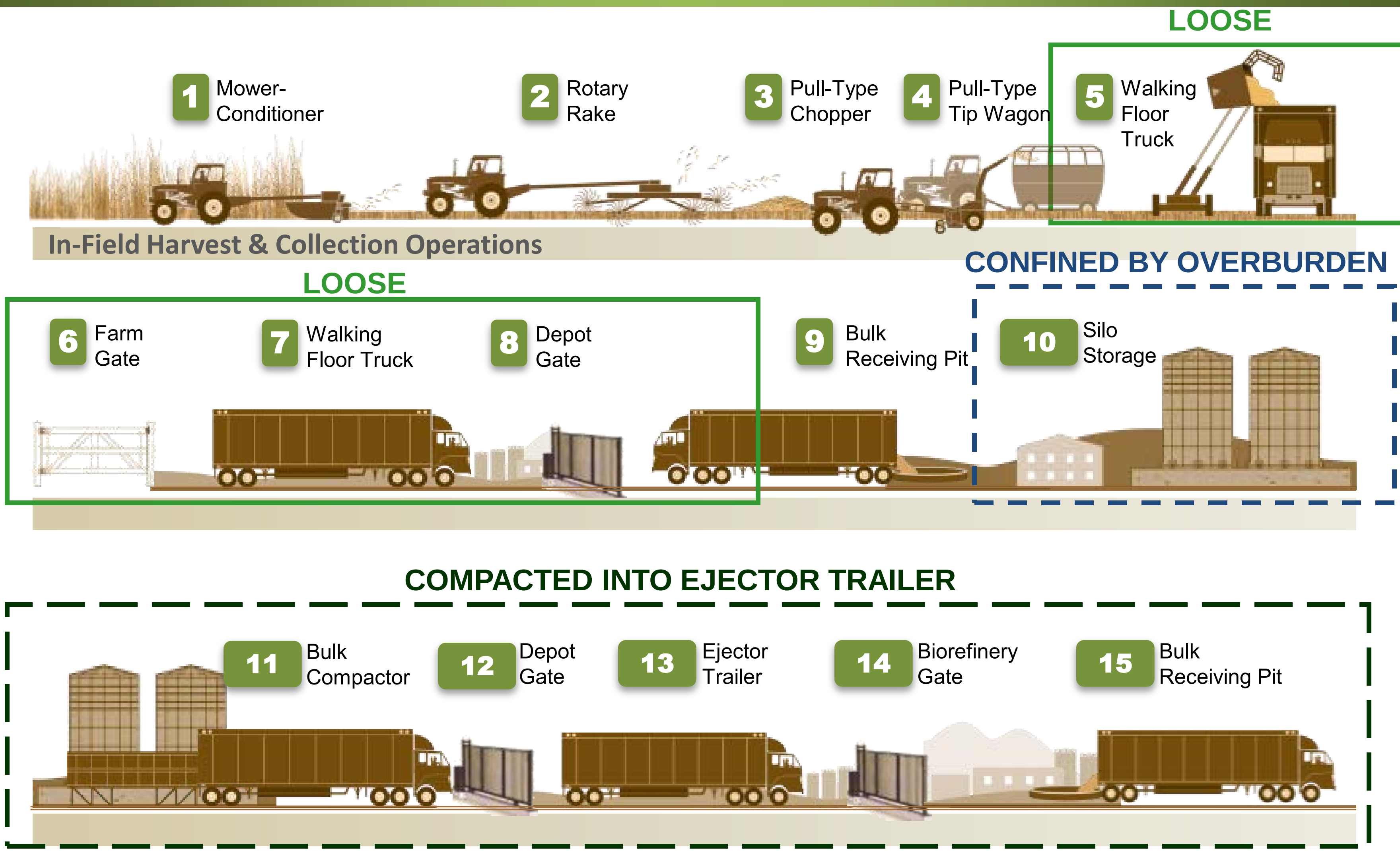
- Develop a bulk-based switchgrass harvest, handling, storage, compaction, transport, and off-load system to supply a demonstration biorefinery
- Determine switchgrass handling efficiencies of the bulk system and identify areas to improve efficiencies with respect to equipment investments and operators
- Determine switchgrass quality associated with the bulk system compared to the current bale system based on ethanol production and potential

1- Approach

- Logistics spans harvest of biomass material standing in the field to conveyance of a uniform, industrial milled product into the throat of a biomass conversion.
- Size reduction is integrated early into supply chain. Compaction process is examined to increase bulk density.
- Unique application of mechanical reclaim, pneumatic conveyance, compaction
- Involvement of wide range of key experts and companies representing span of logistics



2 - Technical Accomplishments



2 – Technical Accomplishments

Range of harvest conditions, including field shape, terrain, distance, day & night

From GPS, GIS, On-site Truck Scales, etc.:

Demo-Scale*			Projected Commercial Scale**		
Operation	**Rate** *(per unit, Dton/h)*	**Efficiency or Utilization** *(%)*	**Operation**	**Rate** *(per unit, Dton/h)*	**Efficiency or Utilization** *(%)*
MoCo, 3-m (1 unit)	17.7	75.9	MoCo, 4-m (17 units)	88	80
Pull-type Forage Harvester (1 unit)	8.4	70.6	Self-propelled Forage Harvester (27 units)	44.6	70
Tip Wagons (3 units)	3.1	64.8			
Bulk-Trailer Trucks, 52 cu-yd, 3.8 Dton/load (2 units)	4.4	69.1	Bulk-Trailer Trucks, 133 cu-yd, 9.7 Dton/load (151 units)	7.8	75
Depot Receiving (1 unit)	8.8	36.6	Depot Receiving, 6 units/depot (30 units/5 depots)	50	90

* 2.85-3.61 Dton/ac

** 8 Dton/ac

** Supplying 410,000 Dton/y of Switchgrass to 32.8 Mgal/y Biorefinery

2 – Technical Accomplishments

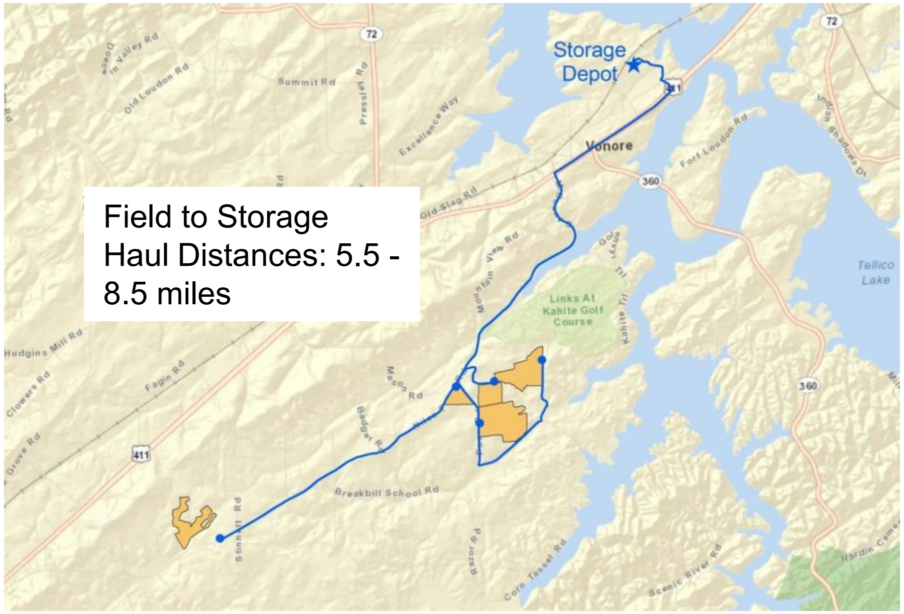
Particle size	Wet Bulk Density* (lb/ft3) (@ 13% m.c.-w.b.)		Demo-Scale Loads* (tons)		Commercial-Scale Loads* (tons)	
	Loose	Compacted	52 yd^3 (Loose)	100 yd^3 (Compacted)	133 yd^3 (Loose)	108 yd^3 (Compacted)
Field Chop	6.20	10.64	4.35	14.36	11.13	15.51
Coarse Tub Grind	4.90	8.61	3.44	11.62	8.80	12.55
Fine Tub Grind	6.00	10.61	4.21	14.32	10.77	15.47

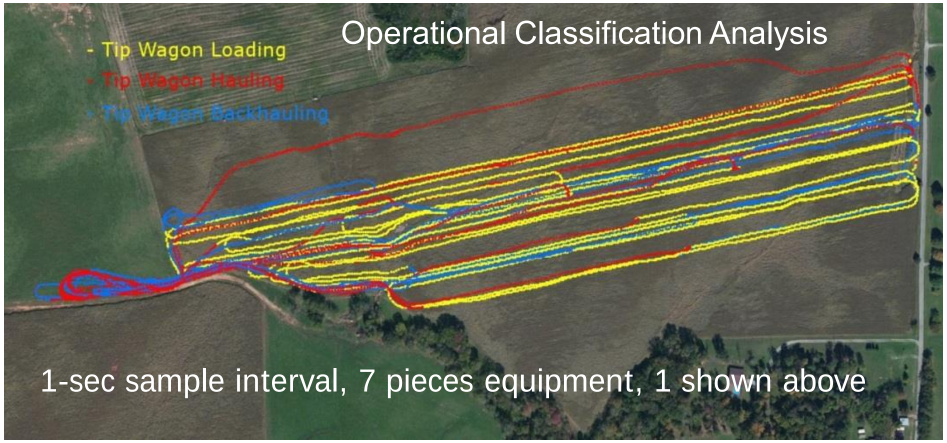
For Comparison

For Comparison

*In practice, fill efficiency affects loads and are taken into account.

2 – Technical Accomplishments





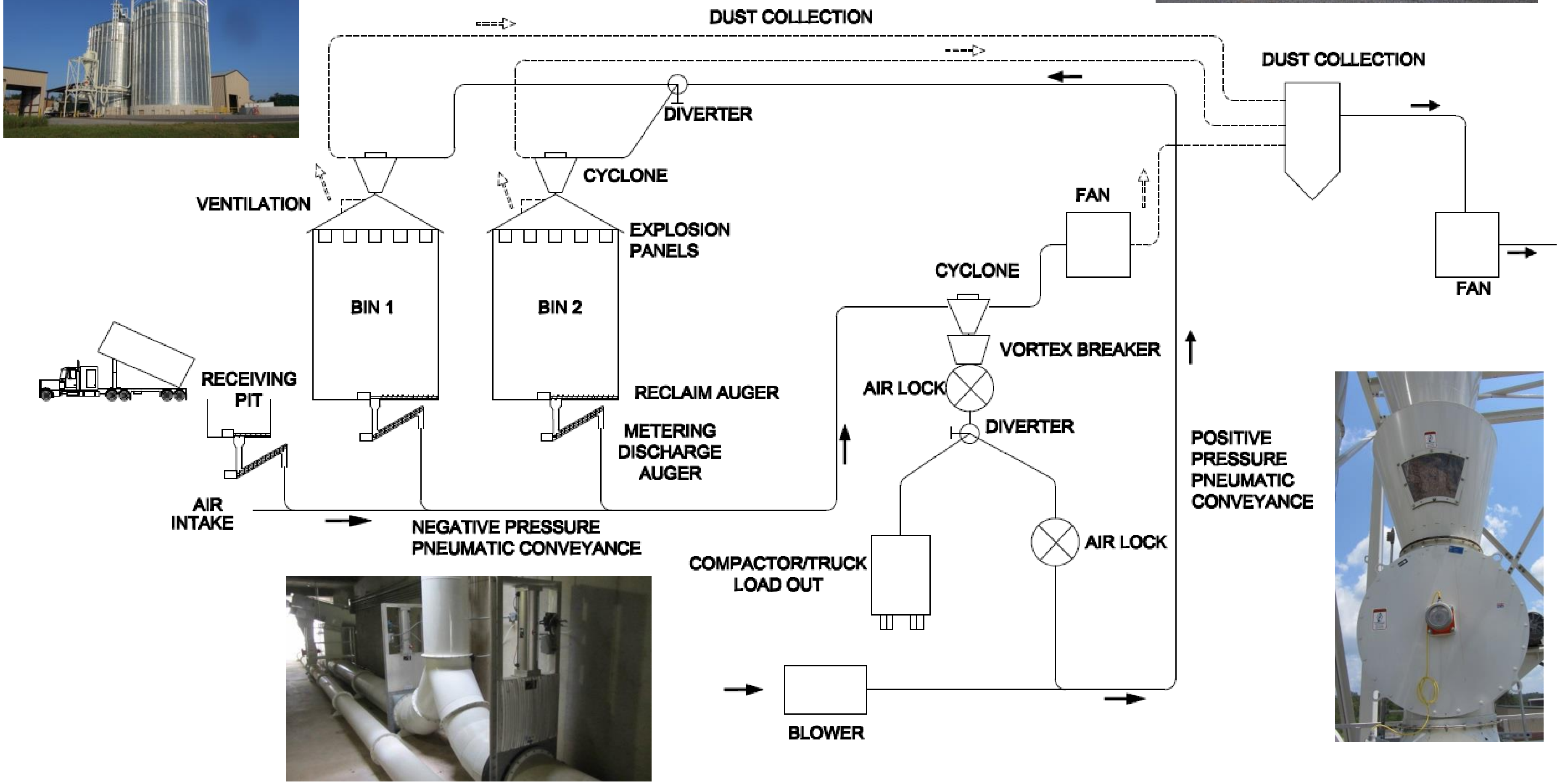
Limiting Factor During Harvest Logistics

	Daily Proportion of time (%) (Calc. for 1-sec resolution)		
	Min.	Avg.	Max.
Forage Harvester (1 unit)	74.3	88.7	97.0
Tip Wagons (3 units)	0.1	1.7	5.1
Trucks (2 units)	1.3	9.6	23.4*

* Caused by receiving startup delay on first day of harvest

2 – Technical Accomplishments

Commissioned receiving, storage, handling, & dust collection systems



2 – Technical Accomplishments

Risk Management

- System design in accordance with appropriate codes
  - International Building Code (IBC)
  - International Fire Code (IFC)
  - National Electric Code (NEC)
  - National Fire Prevention Association (NFPA)
    - **NFPA 61** Standard for Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities
    - **NFPA 68** Standard on Explosion Protection by Deflagration Venting
- Compliance - local authority w/ jurisdiction
- Insurance Risk -Property Specialists review
- Operations – Standard Operating Procedures (SOPs) compliance & education

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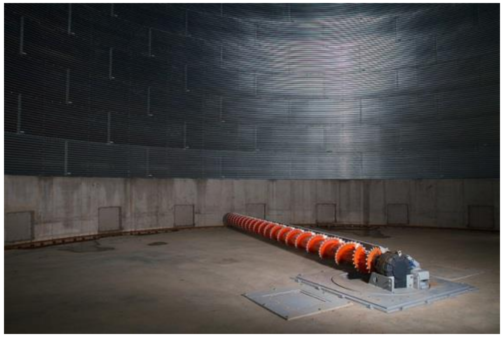
2 – Technical Accomplishments

Bin Load (field chop)	
93% Bin fill	874 tons (13.3% m.c.)
	756 Dtons
Bin top	5.4 Dlb/ft^3
Overall Avg.	8.4 Dlb/ft^3
Bin bottom (est.)	11.3 Dlb/ft^3

Factor	Reclaimer	
	Pit	Bin
Reclaimer Length (ft)	15	30
Max. Screw Reclaim Rate (cfm)	166	166
Max. Screw Reclaim Sweep Rate (ft^2/h, initial setting)	187	336
Max. DESIGN Screw Reclaim Rate (density of 5.5 Dlb/ft^3) (Dton/h)	27.4	27.4

Lessons learned from Storage & Reclaim provide fundamental knowledge to implement increased-scale bulk storage stacks & applicable Stacker-Reclaim technology

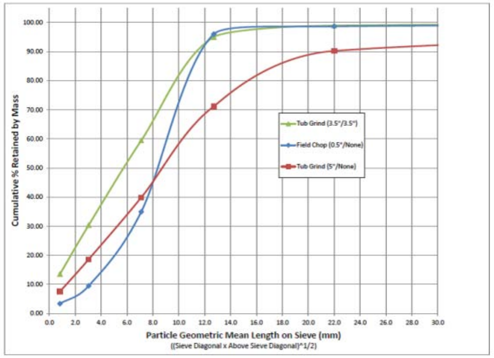
Receiving Pit



Bin

2 – Technical Accomplishments

3 unique particle sizes tested



Device	Material	Overburden (ft)	Avg. Reclaim Rate (Dton/h)	Reclaim Duty Cycle (%)
Bin 1	FC*	85	31.0**	0**
Bin 2	FC	16	29.8**	35**
Bin 2	CTG	19	4.9	99
Bin 2	FTG	16	11.0	75
Receiving Pit	FC	6	22.4	48
Receiving Pit	CTG	6	12.9	57
Receiving Pit	FTG	6	16.7	52

*FC – Field Chop CTG – Coarse Tub Grind FTG – Fine Tub Grind

**Influence of rushing, free-flowing FC bulk during bin discharge, as high as 40 Dton/h – exceeded reclaim design rate of 27 Dton/h

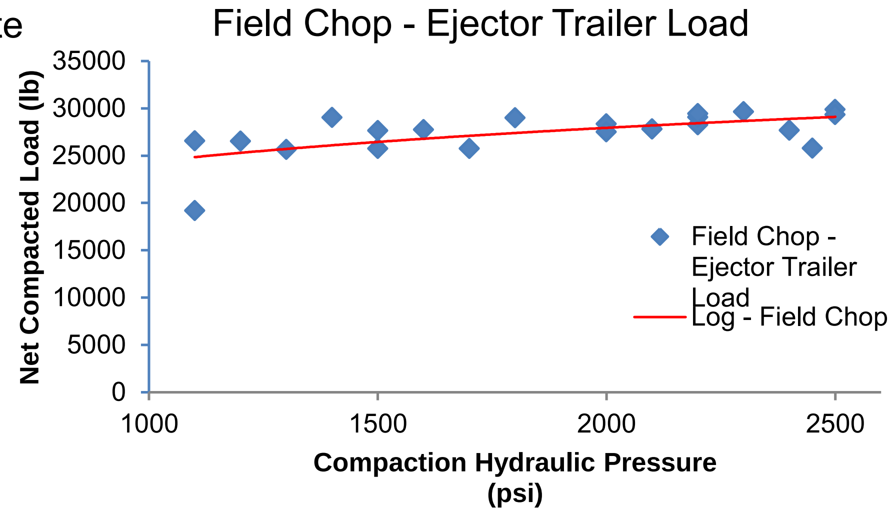
2 – Technical Accomplishments

Bulk Compaction - mobile

Material	Avg. Compaction Rate (Dton/h)	Avg. Ejector trailer Discharge Rate (Dton/h)	Dry Bulk Density (Dlb/ft^3)
Field Chop	34.6	142	9.23
Coarse Tub Grind	8.0*	113	7.49
Fine Tub Grind	10.63*	137	9.22

*Primarily limited by supply rate

Novel means to re-distribute compactor weight during transport



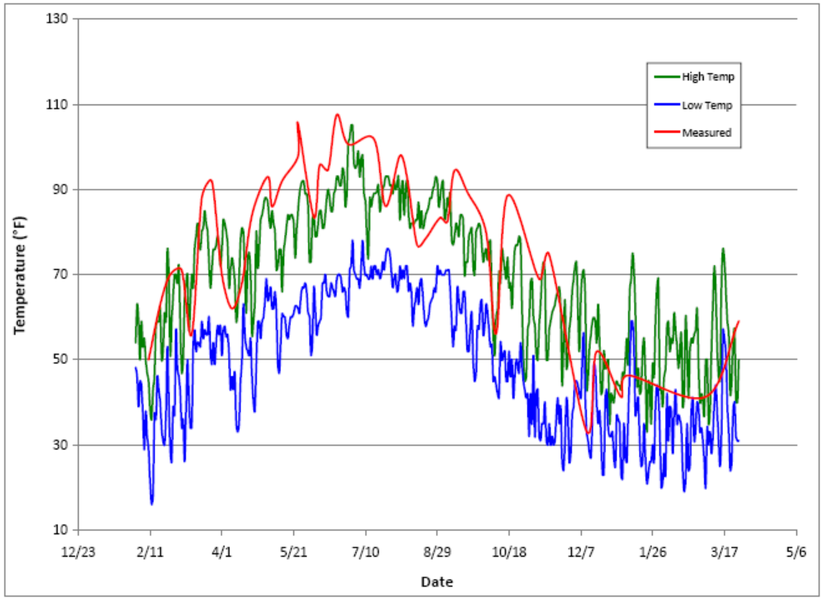
2 - Technical Accomplishments

Harvest
- Moisture content samples for decision to start harvest.

Delivery
- Moisture content samples from each delivered truck load.

Storage
- IR storage and ambient temperatures
- Moisture content and composition samples at storage discharge.

- No detected self-heating during storage & reclaim
- Management of moisture content
  - Forage Harvester (at harvest) ~13.3% (w.b.)
  - After Storage and Handling ~11.3% (w.b.)



2 – Technical Accomplishments

Bulk Flow/ Reclaim/ Handling Experiments

- Randomized Complete Block
- Switchgrass re-circulation
- 3 particle sizes, 4 replications each
- 4-hour experimental unit
- 1-Hz data collection rate (14,400 repeated measures)
- 58-variables for handling system
- Controls system source of many variables
- Focus on power-relations

Example for field chop & coarse tub grind combined data:

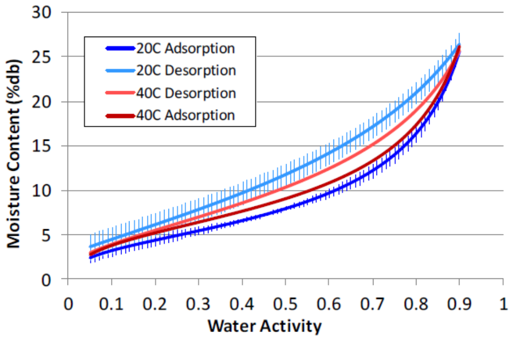
Conveyance Variable	Pearson Correlation Coeff. (P-level)		
	kW-positive Conveyance	kW-vacuum Conveyance	kW-dust Collection
kW-positive Conveyance	1.00	-0.913 (<0.0001)	0.537 (<0.0001)
kW-vacuum Conveyance	-0.913 (<0.0001)	1.00	-0.348 (<0.0001)
kW-dust Collection	0.537 (<0.0001)	-0.348 (<0.0001)	1.00

2 - Technical Accomplishments

- Kice bulk flow handling – pneumatic handling system
  - Vacuum (negative pressure) conveyance (safety in confined areas)
  - Pressure (blowing) conveyance (efficient tube size)
  - Dust collection integrally designed (safety and emissions)
  - Cyclone, Vortex chamber, Airlock concept
  - Initial tests with switchgrass stems up to 8-in length in scale system
  - Design details tweaked during commissioning
  - Current system throughput (ton/h) mostly limited by positive pressure conveyance leg

Underlying mechanism for free-flow FC* compared to CTG* or FTG* is not understood - active effort to find measurement that contrasts flow properties

- INL property measurements to understand rushing, free-flowing FC during bin unload
  - Compressibility
  - Springback
  - Wall friction
  - Flow indices
  - Water activity



*FC – Field Chop CTG – Coarse Tub Grind FTG – Fine Tub Grind

2 - Technical Accomplishments

- DuPont assists by evaluating switchgrass samples for compositional analysis and ethanol potential
  - Comparing bulk-format with baseline bale system
  - Evaluating temporal effect of storage time up to 1 year.
  - No surprises seen thus far in results
  - Switchgrass composition from windrow during harvest are not affected by whether forage harvester or baler is picking up windrow
  - Several publications document switchgrass potential

3 - Relevance

1. Project tackles bulk-format logistics and bulk handling aspects that are applicable to most feedstock supply systems
2. Downstream processing was incorporated early in the logistics system – to reduce often ignored issues with creating feedstock specifications for biorefinery needs
3. Depot format was incorporated into logistics system design
4. Novel densification was examined that still allows economy of bulk handling
5. Bulk-format reclaimer and handling experiments provide detailed data previously not available for industrial scale up
6. A "model energy crop" of perennial grass at low moisture was examined through equipment systems that had limited or no prior experiences and/or data collection
7. Biomass selection, harvest time, and processing method were identified for fundamental advantages in handling opportunities

4 – Critical Success Factors

Project

- Past challenges dealt with by this project were:
  - timely startup, since startup coincided with prioritized Recovery Act projects (6 to 8 month delay in project start up)
  - timely manufacturing of equipment – much was standard equipment, but not stock items
  - timely design and approvals for various permits, codes, jurisdictions, and risk management
  - timely construction of facilities that involved various partners, suppliers, contractors, and natural conditions (karst, weather, etc.)

Adoption/ Commercial Deployment

- Business climate and energy policies impact the bio-energy industry, fiscal stability, and return-on-investment.
- Project increases technical knowledge level of bulk-format and other systems employing bulk handling into the throat of the biorefinery.
  - logistics and handling systems for bulk-format were thoroughly advanced, per previous slides

5 – Future Work

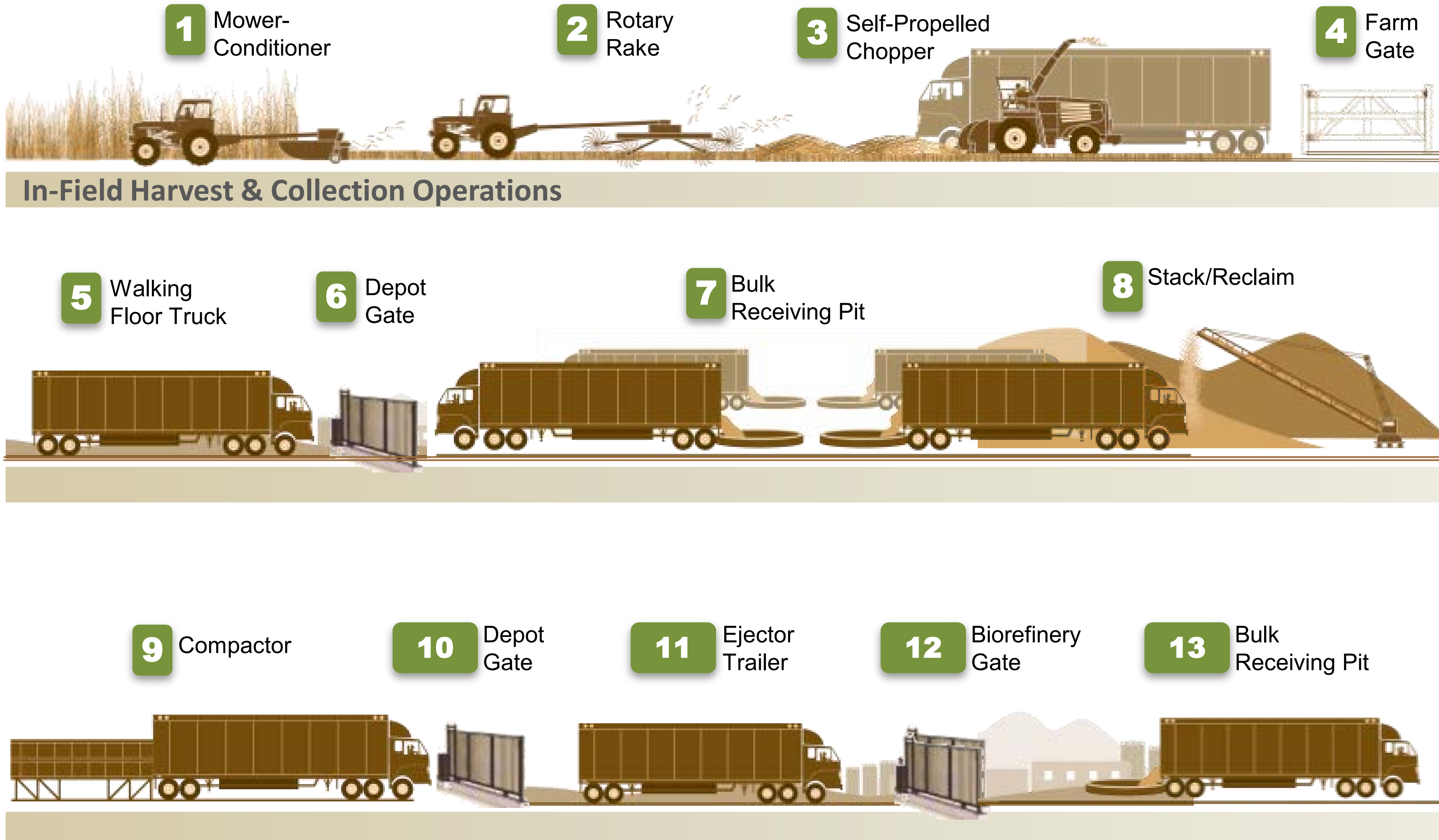
Project

- Project wraps up June 30, 2013, about 1 month away
- Remaining tasks in process for completion:
    - Efficiency and utilization calculations from GPS/GIS
    - Logistics conclusions for improved efficiencies and unit energy (kW-h/Dton)
    - Statistical analysis of replicated handling experiments with emphasis on power and unit energy (kW-h/Dton)
    - Summary of switchgrass quality comparisons between bale and bulk-format

Adoption/ Commercial Deployment

- Stacker-reclaimer using track-less technology to facilitate mobile deployment for tall-stack storage, handling, and out-loading of transport units
- Tall stack and membrane technology for moisture management

Technology Transfer - Commercial Bulk



Technology Transfer - Commercial Bulk

Advantages of bulk-format go beyond cost – since supply of scalable large quantities of uniform, pre-processed feedstock at biorefinery specifications aides risk-management.

Comparison of Feedstock Supply Chain Logistics
--Supplying 410,000 dton/y of Switchgrass to a 32.8 Mgal/y Biorefinery --
--Harvest Window of 371 h/y, Biorefinery Supply Window of 2000 h/y --

Round Bale, Distributed Roadside Storage, Truck Bales 45 miles to biorefinery, Tubground			**Forage Harvester-formatted Bulk**, Truck Loose Bulk 10 miles to 5 Depots, Truck Compacted Bulk 35 miles to Biorefinery		
Logistics Step	Units (n)	Cost ($/dton)	Logistics Step	Units (n)	Cost ($/dton)
Mower-Conditioner cut	17	1.32	Mower-Conditioner cut	17	1.32
Rake crop	17	0.75	Self-Propelled Forage Harvester	27	6.92
Round Bale crop, net wrap	31	6.38	Collect and haul loose bulk in van trailer	151	8.97
Self-load Bale wagon, bales to field edge	31	2.21	Depot Bulk Receiving Station	5	2.91
Tractor loader Stack Bales 3-2-1	31	1.37	Depot Conveyance Receiving	5	1.80
Field Edge Storage - 1-acre Rockbase/ tarp	244	12.11	Depot Conveyance Discharge	5	5.08
Truck field telehandlers to storage sites	1	0.41	Depot Dust Collection	5	2.95
Field telehandler load bales on Truck	5	0.98	Depot Storage - 6-acre Rockbase/ tarp	5	1.49
Truck bales to biorefinery	39	13.06	Depot Stacker/Reclaimer - Stacking	5	1.35
Biorefinery telehandler offload bales	6	1.18	Depot Stacker/Reclaimer - Reclaimer	5	8.19
Biorefinery telehandler - bales to grinder	6	1.18	Bulk Compactor	7	1.57
Tubgrind bales	12	13.51	Ejector Trailers for compacted bulk format	32	11.10
Dust collection	3	1.77	Biorefinery bulk receiving	1	0.73
			Dust collection	2	1.18
Total		56.23	Total		55.56

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Summary

1. Approach
   - This project dealt with a most comprehensive supply chain to handle feedstock delivered at biorefinery specifications
2. Technical accomplishments
   - monitor/ classify logistics operations
   - lessons for development of advanced turn-key, feedstock supply systems
   - contrast loose- versus compacted-bulk conditions
   - biomass reclaiming and handling - discovery of free-flow field chop
3. Relevence
   - results apply to most feedstock supply systems, through bulk handling aspects
4. Critical Success factors & challenges
   - construction challenges and harvest logistics – obstacles were overcome
5. Future Work
   - project is near end, data wrap-up is being conducted
6. Technology transfer
   - a platform for enhancing uniform-format feedstock supply was identified for high-quantity handling with bulk stacker – reclaimer technology

Systems Matter!

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Questions?

www.biomassprocessing.org

www.biomasslogistics.org

www.generaenergy.com

Response to 2011 Review comments

- Under 2. Technical Progress and Accomplishments
  - Comment: "It will be hard to finish by 2012." "Aggressive target timeline is noted."
  - Response: Project start was delayed 6 to 8 months due to DOE priority of Recovery Act projects, even though this project required substantial construction and dependence of harvest campaign and handling experiments on system being constructed. Excellent progress was made on this complex project due to responsive project management and the fact that excellent partners had been selected. A 6-month no-cost project extension was requested and granted to allow 1 full year for material storage and subsequent evaluation.

Response to 2011 Review comments

Under 4. Critical Success Factors

Comment: "It is unclear how the delivered material, which appears to re-fluff on delivery will be integrated with storage activities at conversion facilities."

Response: Field chopped switchgrass at low moisture has a natural, loose high bulk density compared to other biomass. Confining pressure is provided by various means purposely engineered into the system. A simple mechanism is through the overburden-effect that increases bulk density. The bulk compactor technology was also proven effective. A strength of the project is using handling equipment that is typically used at receiving stations of biomass conversion facilities. This project more thoroughly evaluated the supply chain to the biorefinery.

Response to 2011 Review comments

Under 5. Technology Transfer and Collaborations

Comment: "No mention of technology transfer." "Tech transfer should be fairly natural…"

Response: As part of the Biomass Innovation Park, project technologies receive much visibility through public events (2 biomass field days since last review) and nearly daily visits by various firms, entities, and organizations. As with any business venture and activity, intellectual property and agreements are regularly executed by Genera and are not advertised. Much interest has been demonstrated regarding the bulk-format and handling technologies.

Publications, Presentations, and Commercialization

- Womac, A.R., W.E. Hart, V.B.S. Bitra, and T. Kraus. 2012. Biomass harvesting of high-yield low-moisture switchgrass: equipment performance and moisture relations. Applied Engineering in Agriculture 28(6): 775-786.
- Bitra, V.S.P., A.R. Womac, Y.T. Yang, P.I. Miu, C. Igathinathane, N. Chevanan, S. Sokhansanj. 2011. Characterization of wheat straw particle size distributions as affected by knife mill operating factors. *Biomass and Bioenergy* 35(8):3674-3686.
- Chevanan, N., A. R. Womac, V.S.P. Bitra, S. Sokhansanj. 2011. Effect of particle size distribution on static and tapped densities of selected biomass after knife mill size reduction. Applied Engineering in Agriculture 27(4):631-644.
- Womac, A.R. 2012. Biomass feedstock supply logistics. Editors: Kent Rausch, Vijay Singh, and Mike Tumbleson, Program Proceedings of The Science and Engineering for a biobased industry. Aug 7, 2012, Waterfront Centre, 800 9th Street SW, Washington DC USA.
- Groothuis, M. and A. Womac. 2012. Bulk-format switchgrass harvest system logistics. Paper No. 121337867, ASABE, St. Joseph, MI.
- Groothuis, M., A. Womac, G. Braswell, V. Bitra. 2011.Compaction experiences with bulk-format switchgrass in commercial transfer systems. Paper No. 1110819, ASABE, St. Joseph, MI,
- Womac, A.R. 2012. Feedstock pre-processing and preparation - an engineering perspective. Biomass Field Day, October 24-5, Vonore, TN
- Womac, A.R. 2012. Biomass feedstock supply logistics. S1041 Multistate Project Symposium, Washington, D.C. August 7, 2012.
- Womac, A.R. 2012. Bulk-format logistics system for low moisture switchgrass. Special Session on US-DOE High Tonnage grant projects, Annual International Meeting of ASABE, Dallas, Tx., July 31, 2012.
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- Womac, A.R. 2011. Development of a bulk-format system to harvest, handle, store, and deliver high-tonnage low-moisture switchgrass feedstock. DOE Biomass Platform Review, Annapolis, Maryland. April 8, 2011.
- Womac, A.R. 2011. Development of a bulk-format system to harvest, handle, store, and deliver high-tonnage low-moisture switchgrass feedstock. Agricultural Equipment Technology Conference, Atlanta, GA. January 7, 2011.
- And others…